KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

POTABILITY OF WATER FROM BORE HOLES AND HAND-DUG WELLS IN TWO PERIPHERAL COMMUNITIES OF JACOBU IN THE AMANSIE CENTRAL DISTRICT, GHANA

BY

VIDA SARPONG

JULY, 2014

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A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

By

VIDA SARPONG

JULY, 2014

DECLARATION

I hereby certify that, I have personally undertaken the study herein and this thesis is my original work submitted towards the MSc Environmental Science degree under supervision and that, to the best of my knowledge it contains no entire material previously published, nor material which has been wholly accepted for the award of any other degree of the University or elsewhere, except where due acknowledgement has been duly made in the text.

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Head of Department	Signature	Date

ABSTRACT

The drinking suitability of water collected from seven different sources (borehole and dug out wells) in Aboabo and Pataase in the Amansie Central District of the Ashanti region of Ghana were investigated by determining the microbial quality and some physicochemical parameters using standard analytical techniques. The results of physicochemical parameters (pH, temperature, turbidity, conductivity, alkalinity, and amount of oxygen) revealed varying concentration in relation to required standards. Mean conductivity ranged from 68.36 µS/cm to 581.22 µS/cm, with most of the other parameters measured below the standard permissible range of WHO and Ghana Standards. pH was slightly acidic and below the WHO permissible range. All the hand-dug wells and boreholes with the exception of borehole BHA2 showed evidence of faecal contamination. The counts of the total coliform, faecal coliform and the *E. coli* differed significantly ($p = 0.005$) between the various water sources sampled. It is imperative from this study that water from the various sources should be treated before drinking and also monitored regularly in order to put in measures to reduce or identified pollution indicators and pathogens that may pose some dangers to the health of people living in this area.

ACKNOWLEDGEMENT

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DEDICATION

Thus far has the LORD brought me! This work is dedicated to my family.

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CHAPTER ONE

INTRODUCTION

Water with its unique physical and chemical characteristics in the liquid state is indispensable for the continued existence of most living organisms and in adult humans, forms up to 70% of the bodyweight. It is needed for the preservation of good living; however, this esteemed asset is progressively being debilitated by different human activities combined with anthropogenic development and in this way the need for safe and quality water is of prime relevance for drinking, residential purposes and financial exploits. Considering its value, the availability and quality of water especially drinking water is very critical for the overall socio-economic development of any society and, should engage the attention of individuals, groups, government and non-governmental organizations (Adetunde and Glover, 2010).

Unfortunately, for many countries in the world including Ghana a large proportion of its citizenry do not have access to potable drinking water. Only nineteen percent (19%) of Ghanaians have potable water connected to their homes from the Ghana Water Company Limited (GWCL), the main service provider in Ghana while the others obtain water from alternative sources such as protected and unprotected wells, rivers, streams etc. (MDGs Africa, 2008). Water from the GWCL or municipal water is treated according to standards to provide public health benefits such as prevention of water borne diseases; however, water from other avenues including hand-dug wells and boreholes are generally managed by the communities or the owners without any monitoring in terms of its quality.

Although quality of source water is very important, it does not necessarily translate into full health benefits if other precautions relating to transportation from source to household, storage and sanitation/hygiene are not regarded as important. Water quality can deteriorate during the course of collection, transport and home storage (Oswald *et al.,* 2007)

Water is an environment for many microorganisms, some of which include both pathogenic organisms such as bacteria, viruses, protozoans, and worms which cause diseases in humans. Disease causing microbes such as those that may be associated with diarrhoea-related illness cholera are normally come from humans (Dick and Field, 2004) and other contaminated sources of water for consumption. All around the world, bad quality of drinking water combined with poor sanitation kills not less than 1.6 million kids below five years old annually with 84% of them dwelling in poor regions (WHO and UNICEF, 2006). High pervasiveness of the watery stools or dysentery among children and newborns can be ascribed to the utilization of untreated water and unhealthy activities (Oladipo *et al.,* 2009; Tortora *et al.,* 2002)

Previously, most of the rural communities did rely on rivers and streams and in rare cases wells, as their main source of drinking water, none of which guarantees potable water. Surface water resources thus constituted the basis of existence for a majority of rural and some town dwellers in West Africa (Edwards, 1993). However, following the deterioration in quality of surface water resources such as rivers and streams, resulting from anthropogenic activities including mining, deforestation, agricultural production and the discharge of harmful sewage and effluent into the water bodies, bore holes and hand-dug wells have become the most commonly preferred water sources. The inclination for groundwater as a wellspring of potable water poor regions is as a result of its moderately preferable quality over river and stream water. However, these groundwater resources may be polluted from different sources and are as well threatened by the unsafe means of getting rid of untreated fecal matter and refuse into waterbodies, in light of the absence of sufficient waste treatment installations (WRC, 2000), and the ineffective administrative system used in collection and disposal of household, urban and industrial garbage which make their way into the aquatic ecosystem, and additionally from disintegration of stream catchments as an aftereffect of clearing land for crop cultivating, timber and woodlots, and mining (WRC, 2000). These pollutants/residues could potentially reach groundwater (Obiri-Danso *et al.*, 2010) by infiltration into the aquifers; the indiscriminate use of agrochemicals for example, have been implicated in the amassing of levels heavy metals in cultivated soils and pollution of both rivers and underground water (Atafar *et al.*, 2010). The afore mentioned causes have contributed to the increasing levels of diseases transmitted through contact with contaminated water such as typhoid fever and cholera encountered mostly in the under-developed and the developing world (Edwards, 1993). In 2010 the WHO/UNICEF Joint Monitoring Programme indicated that nearly 3 billion people are without enhanced public health and nearly one billion individuals lack access to well-sourced potable water and this situation is undesirable (WHO/UNICEF, 2010).

Mining activities, generally gold mining operations, can have negative impacts on both society and the environment especially water bodies. Such activities that affect water quality include the disposal of waste rock, tailings deposition, and effluent discharges from different stages of mineral processing (Dick and Field, 2004). Effluent produced from waste rock dumps for example, has a potential to cause Acid Mine Drainage (AMD) into stream and river waters. Gold mining operations can have negative impacts on both society and the environment (Koryak**,** 1997; Ayedemi *et al.*, 2007).

Uncontrolled mining operations could heavily pollute the environments with consequent destruction of the ecosystem that affect species biodiversity. Gold mining on the medium and small level is presently considered to contribute about 12% of the world's gold production or nearly 400 tons annually (Telmer and Veiga, 2008). These small-scale mining activities are on the increase in Ghana with operations usually located close to and supported by water bodies. The miners generally dig up river channels, banks and their floodplains as well as surface trenching, to recover the precious stones and these cause serious environmental and health challenges.

Pollution of water resources arising from the increase in various anthropogenic activities along river courses and the disturbances of the ecosystem especially in developing countries, may contaminate both groundwater and surface water resources. This makes it imperative for regular monitoring of water quality, especially for drinking and domestic purposes for appropriate management choices for improving or protecting the quality for its intended uses.

1.1 Justification

Water resources are subject to ever-growing demand and increasing pollution pressures for human consumption and for other domestic uses. There is always an ever increasing use of groundwater by rural and peri-urban inhabitants, as treated water sources are lacking for such communities coupled with the destruction of rivers and streams which were important traditional sources of water. The communities of Aboabo and Pataase in the Amansie

Central district of the Ashanti Region have no standard treated pipe borne water supply systems, thus the communities depend entirely on hand-dug wells and boreholes solely for water. Despite the provision of boreholes a section of the people of Pataase and Aboabo especially, still depend mainly on the hand-dug well as a primary source of potable water and also for other domestic purposes.

These alternative sources are to a large extent exposed to contaminants such as bacteria, viruses, metals, nitrate and salts which could make the water not good for drinking and domestic chores. Thus the quality of such sources is often very variable and they frequently show gross faecal contamination especially during rainy seasons (Barrett *et al.,* 2000) as a result of unhygienic sanitary practices, indiscriminate dumping of waste and subsequent pollution of water enhancing the infiltration of harmful organisms and compounds into the groundwater. Such alternative water sources are public amenities situated within the catchment area of the home, necessitating collection and carrying from the source of water supply and consequent storing of water in the home thus providing further chances of contamination. The quality of water accessed for use is consequently an important public health gauge (Trevett *et al.,* 2005; Gundry *et al.,* 2004).

Considering the indiscriminate disposal of waste (humans and livestock), as well as the illegal mining activities which disturbs the geology and also renders the main stream on which some of the inhabitants of Aboabo and Pataase depend polluted, contamination of underground water is possible in the area. Since information about suitability of drinking water sourced underground in the area is lacking, the need therefore arises to frequently check the quality of such drinking water sources in order to provide measures to moderate the occurrence of water related diseases. Thus the study sought to determine the potability of hand-dug wells and borehole water sources within Aboabo and Pataase communities in the Amansie Central District of Ashanti region.

1.2 Objective

The aim of the study is to determine the suitability of drinking water from various sources (hand-dug wells and bore-holes) and at the point of use in the Aboabo and Pataase communities in the Amansie Central District of Ashanti region.

1.2.1 Specific Objectives

These are to determine the;

i. physicochemical parameters such as pH, Total Dissolved Solids, Electrical Conductivity, Turbidity, Total hardness, Nitrate, Fluorides and Nitrite content of water from boreholes and hand-dug wells.

ii. presence and counts of Total and Faecal coliforms and *E coli* in the water from boreholes and hand-dug wells.

iii. microbial quality of ready-to-drink water in receptacles in selected households

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Resources

A lot of water is stored up in the ground. A large portion of underground water originates from rainfall that percolates from the face of the ground. The water moves, normally pulsating, but this forms a portion of the hydrological cycle. The topmost stratum of the earth constitutes the region with differing quantities of water availability which does not yet fully occupy soil interstice, known as the unsaturated zone. Beneath this stratum is found the saturated zone or layer, that has water soaked sandy particles occurring between majority of pores, breaks, and interstices (Kara *et al.*, 2004) which forms the basis of groundwater. Globally, fresh ground water constitutes about 10,530,000 Km^3 by volume out of a total of about one billion Km^3 (Table 1).

Table 1: Estimate of Global water distribution

Water source	Water volume, in cubic miles	Water volume, in cubic kilometers	Percent of total water	Percent of total freshwater
Fresh groundwater	2,526,000	10,530,000	0.8%	30.1%
Groundwater	5,614,000	23,400,000	1.7%	--
Total global water	332,500,000	1,386,000,000	--	--

Source: (Gleick, 1996).

As a nation Ghana is well supplied with groundwater and Perennial Rivers, even though occasional deficiencies do occur often. The mean yearly precipitation varies from 2,150 mm in the farther southwest section of the nation, decreasing gradually eastwards and northwards to 800 mm in the southeast and around 1,000 mm in the upper east of the nation (WRC, 2000).

The country is supplied with water by three major riverine bodies; the Volta, the south-western and the coastline river basin systems. These systems cover 70, 22 and 8 percent of the entire land mass of Ghana respectively (WRC, 2000). Neighboring Togo, Mali, Côte d'Ivoire, Benin and Burkina Faso share the Volta River basin with Ghana. The other two river systems in the south-western system are also shared with other countries – it shares the Bia River with Côte d'Ivoire, whereas the lower portions of the Tano River a section of the Côte d'Ivoire border. Data available at the Water Resources Commission (WRC) [2000] indicates that the river bodies have a total yearly surface water volume of 56.4 billion m^3. About 73.7 %, 29.2 % and 6.1 percent of Ghana's yearly run-off is supplied by the Volta, south-western and coastline systems respectively (Ministry of Works and Housing, Ghana, 1998). Ground water quality as resources in Ghana is usually potable except for some occurrence of limited contamination by large concentrations of iron and arsenic, in addition to high contaminations with minerals including total dissolved solids, particularly in some coastline geological forms. (WRC, 2000).

2.2 Surface Water

Surface waters comprise of lakes (including ponds), reservoirs, streams, rivers and wetlands which our entire existence have depend on and profited from one generation to another. River bodies are significant freshwater resource for human beings (WHO, 2004a). However water quality issues have increased over the years in light of the expanded development and convergence of human and industrial settlements (WHO, 2004a).

The country's water assets have come under intensifying risk of contamination in the past few years because of fast anthropogenic changes. This has concurrently occurred with the formation of human settlements deficient of proper sanitation facilities. Numerous such settlements have been created with no appropriate water supply and sanitation systems. Individuals living in these places, and in addition to those downstream, regularly use the polluted surface water for drinking, entertainment and as plant watering system that brings about circumstances that represents a genuine sanitation danger to the general population (Verma and Srivastava, 1990). Contaminated water constitutes an imperative vehicle for spreading pathogenic organisms. In under-developed nations 1.8 million individuals with majority being children suffer grave consequences of water-related sicknesses (WHO, 2004a).

Some factors impact the chemical nature of water. Gibbs, (1970) hypothesized that rock weathering, atmospheric precipitation, evaporation and crystallization regulate the chemical nature of surface water. The effect of geology on biochemical nature of water been well studied (Gibbs, 1970; Langmuir, 1997; Lester and Birkett, 1999). The impact of soils on water quality is extremely complicated and can be attributed to the mechanisms controlling the reaction of chemicals between the sediment and water (Hesterberg, 1998). Aside the common factors affecting water quality, human activities, for example, residential and farming activities affect adversely stream water quality. Consequently, it is imperative to conduct water quality appraisals for viable management of rivers, ponds and lakes.

2.3 Groundwater Development

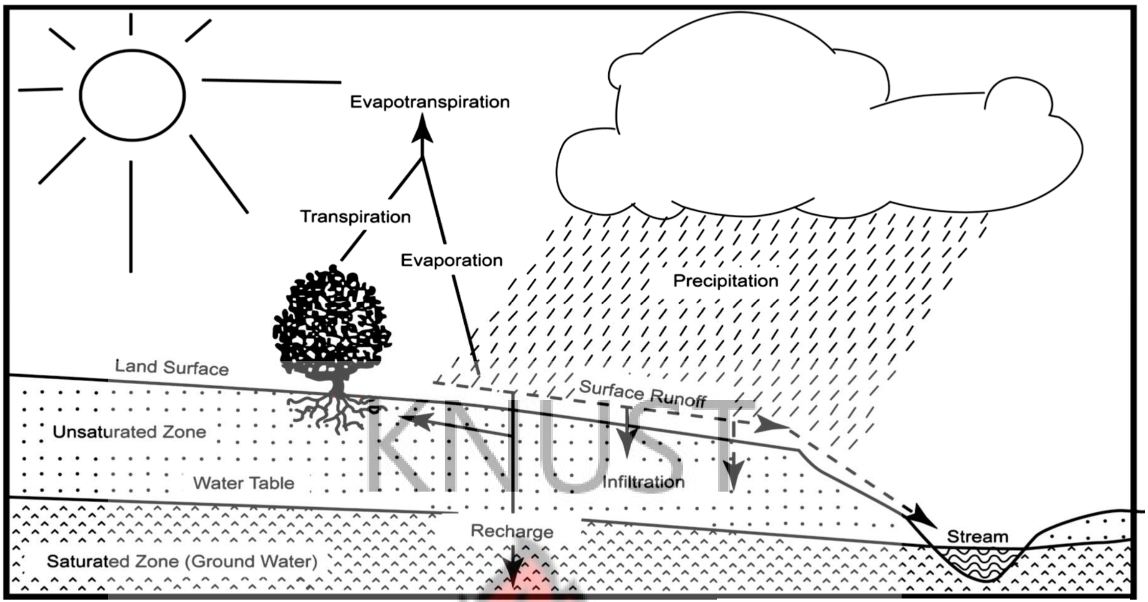
Water contained in the pores of soil or in aquifers is called groundwater (Appelo and Postma, 1993). Groundwater as defined by Falkenmark (2005) is the water confined below the earth crust in rocks and soil, and is the water that collects underground in aquifers. The constitution of freshwater in the biosphere is made up of 97 percent groundwater and this forms a significant source of drinking water in a lot of habitats (Falkenmark, 2005). In various parts of the globe, groundwater sources form the absolutely essential resource for the provision of domestic-water for drinking, especially in zones having restricted or contaminated sources of surface water. For some groups, it might be the main financially practical alternative. This observation according to Falkenmark (2005) is partially true as groundwater is characteristically quite stable in its physical quality and lower microbial numbers than surface waters.

The quality of ground water, mainly shallow ground water, is fluctuating due to human activities. According to Appelo and Postma (1993), underground water to a lesser extent is vulnerable to microbial contamination than river and stream water in light of the fact that, the majority of the microscopic organisms are sieved by the sediments and rocks via which ground water emanates. Moreover, aquifers are frequently very much secured by layers of soil and silt, which adequately screen water as it permeates through them, resulting in the elimination of particles, disease causing microorganisms and chemical constituents. Numerous microscopic dissolved ions and debris from living organisms are found in ground water in different amounts. Majority are innocuous or even gainful; however they occur rarely, others are harmful, and a couple may be profoundly toxic.

2.3.1 Groundwater Recharge

The potential for characteristic groundwater restoration starts with precipitation (downpour, snow, hail, slush). A portion of the precipitation never saturates the soil, however it rather leaves the soil as surface spillover. The water that saturates the earth is by percolation. A portion of the water that penetrates returns to the biosphere through evapotranspiration. Evapotranspiration implies the loss water into the atmosphere from cultivated regions by dissipation from the soil and plant surfaces and soil water that is absorbed by plant roots and lost through plant leaves or spines. Deep percolated water that does not came back to the environment by evapotranspiration moves descends into soil and, after collecting in the saturated zone, gets to be ground water (Figure 1). The water in the ground could be in a parent rock material that is either an aquifer or non-aquifer, contingent upon whether it can yield substantial amounts to wells (Charles *et al.,* 1993).

Notwithstanding being a source water for wells, groundwater can likewise serve as base supply to streams, wetlands, and other water bodies, specifically influencing the nature and geomorphology of these assets.



Source: Charles *et al*., 1993

Figure 1: Groundwater Recharge in the Hydrologic Cycle

The feasibly negative effects of land use in an area on groundwater refill have long been known. Development of land for human activities that protect porous soils with impenetrable surfaces lessens the soil's penetrability through adverse impact and irreversible hardening may decrease the rate of groundwater restoration. Such depletions in groundwater stores can negatively affect streams, wetlands, and other water bodies by decreasing the volume and rate of base supply to such resources. Decreases in groundwater restoration to aquifers could likewise negatively affect the refill of water resource in wells.

2.3.2 Groundwater Supplies

Groundwater is defined as water contained in the pores of soil or in aquifers (Appelo and Postma, 1993). About 97 percent of worldwide freshwater is groundwater and is an essential wellspring of quality water in several places of the world (Falkenmark, 2005). In some regions of the biosphere groundwater reservoirs are the absolute most vital source for the generation of drinkable water, especially in places with constrained or contaminated surface water resources. For some societies it might be the main monetarily reasonable choice. This as indicated by Falkenmark (2005) this is to a limited extent in light of the fact that groundwater is ordinarily of a better steady nature with preferred bacterial quality over river water and is an essential wellspring of savoring water numerous areas of the world (Falkenmark, 2005). For some groups this kind of water might be the main monetarily reasonable choice. This as indicated by Falkenmark (2005) is to a limited extent in light of the fact that groundwater is ordinarily of a more steady quality and preferred microbial quality over surface waters. Another name for ground water is the 'shrouded ocean' –as a result of its vast quantity, and concealed in light of the fact that it is not seen or accounted for, in this manner contamination pathways and procedures are not promptly identifiable (Chapman, 1992). The situation lays bare a key issue in the utilization of aquifers as potable water sources, where specific consideration is expected to identify whether the general presumption of groundwater being potable is legitimate in individual situations. Groundwater frequently requires next to zero treatment to be suitable for drinking though surface waters for the most part should be dealt with, regularly broadly. It is essential in this manner that the nature of groundwater is ensured if general quality or desired nature is not to be traded off. Whilst there is an extensive volume of groundwater in this 'concealed ocean', getting to it requires burrowing or boring through the ground and into an aquifer. Its renewal however happens gradually – at rates fluctuating between areas in this manner overused or misused can promptly happen, carrying with it extra quality deliberations.

2.3.2.1 Boreholes (Tube wells)

A borehole is a tight tube burrowed in the ground and could be used for some purposes in various explorations, boreholes can be used for oil detection, auxiliary bolster, geography examinations, water for plant watering system, water for drinking and additionally water for fire stations.

Water boreholes can meet a wide range of needs however the most well-known borehole systems are for residential/industrial purposes especially drinking and domestic. They could likewise be utilized for cultivation and industrial purposes. Boreholes can be burrowed vertically or on a perpendicular plane (otherwise called directional boring), boring for water requires vertical borehole boring gadgets. There are likewise a wide range of sorts of water drill opening boring machines. There is the rotational boring where a long tube with a cutting head on it is "penetrated" into the earth crust. This is predominantly utilized if the topography is very well examined as the penetrating procedure is very quick. There is in like manner the most generally perceived burrowing framework which has been used for more than 100 hundred years. This incorporates a tripod being raised over the borehole burrowing site and a significant long metal bucket is lifted and dropped to the ground, when lifted up a fold then closes and when the can is lifted up, conveys the earth up with it. This is the safest method for drilling water in different explorative situations. The drag driller has to mull over the different rocky layers and profiles being infiltrated to a high point to ensure there is a functioning water drill hole.

2.3.2.2 Dug Wells

Dug wells are burrows in the ground tunneled by scoop or escavator. Obviously, a dug well is dig out beneath the groundwater level till it gets nearer water above the digger's shielding rate. The well is consequently reinforced on the inside with stones piece, tile, or cementing materials to avert any breakdown. It also further secured with a top of wood, stone, or bond. Since digging beneath the ground water table is somehow tedious, dug wells are not very common. Normally, dug wells are between 10 to 30 feet deep from top to bottom. Being so shallow, tunneled wells have the most shocking peril of getting fouled especially those in polluted circumstances.

2.3.2.3 Springs

A spring is a water asset sourced when the edge of a slope, a valley base or other sections meets a streaming assemblage of groundwater at or beneath the neighborhood underground surface below which the ground is wholly saturated with water. A spring is the consequence of an underground layer yielding ground water being filled to the extent that the water floods the area surface. They run in size from discontinuous leaks, which stream when much rain, to tremendous pools streaming a huge number of gallons every day. Springs are not constrained to the Earth's surface, however. As of late, researchers have found hot springs at profundities of up to 2.5 kilometers in the seas, for the most part along mid-sea fractures (spreading edges). The boiling hot water (more than 300 degrees Celsius) originating from these springs is additionally rich in minerals and sulfur, which brings about a special environment where unordinary and outlandish sea-going life appears to flourish.

2.4 Factors that affect the Quality of Water

Water quality is characterized with regards to the physical, organic and chemical substances in water. The quality of streams and lakes varies with the period and geographic ranges, notwithstanding when there is no contamination present. Just one indicator is enough to measure and establish potable nature of water. Case in point, water suitable for drinking can utilized for watering system, however water utilized for watering system may not meet drinking water rules. Water quality rules give essential investigative data about water quality parameters and biologically important toxicological limit qualities to secure particular water employments (APHA, 1992).

Another factor that affects water quality is the surface water from developed settlements. The surface water contains eroded materials from the streets and convey them to another river or stream. Settlement run-off affects the quality of water in streams and ponds by raising the levels of foreign materials such as animal excreta (faecal coliform and other pathogens), soil particles, nutrients like phosphorus or nitrogen, petroleum products, and gravels. Manufacturing, farming, mineral exploration, as well as cultivation practices also considerably impact the nature of streams, groundwater and ponds. For instance, agricultural activity can intensify the levels of suspended soil particles, nutrients and pesticides. Manufacturing practices can upsurge levels of suspended soil particles, toxic and metal compounds, ambient kinetic energy, and decrease the amount of oxygen in the water body. Every one of these occurrences can have a detrimental effect on the aquatic ecosystem as well as make water undesirable for possible uses (Oregon Department of Environmental Quality, 2004).

2.4.1 Natural processes affecting Water Quality

Water quality is influenced by an extensive variety of natural and human impacts. The most imperative of the regular impacts are geographical, hydrological and climatic, since they influence the amount and the nature of water accessible. Their impact is for the most part most prominent when accessible water amounts are low and greatest use must made of the insufficient asset; for instance, high saltiness is a continuous issue in dry and beach front zones. In the event that the budgetary and economic assets are accessible, seawater or saline groundwater can be desalinated yet much of the time this is not sustainable. In this way, despite the fact that water may accessible in satisfactory amounts, its inadmissible quality restricts the uses that can made of it. In spite of the fact that the normal environment is in consonance with characteristic water quality, any noteworthy changes to water quality will for the most part be troublesome to the biological system (Meybeck and Helmer, 1996).

2.4.2 Water Pollutants and Control

Control of water contamination has come to prime significance in developed and various emerging nations. The counteractive action of contamination at source, the preliminary standard and the former permitting of wastewater releases by economic and industrial giants have ended up contributing to key components of meaningful approaches for avoiding, checking and lessening inputs of toxic contents, supplements and other toxins from point sources into water bodies. In various developed nations, and in addition a few nations experiencing significant change, it has reached the level that basic practices as far as possible for releases of dangerous substances on the done with best accessible innovation. Such hazardous water poisons fuse materials that are deadly at lessened levels, mutagenic and tumor inducing, teratogenic as well as can be bioaccumulated, especially when they are not easily broken down. Remembering that the final objective is to reduce levels of nitrogen, phosphorus, and pesticides which are of diffuse sources (particularly countryside areas) to river basins, natural habitat and cultivating activists in a number of countries are agitating for the need to use most proficient biological activities (Enderlein, 1996). In a few circumstances, significantly stricter prerequisites are vital. An incomplete restriction on the utilization of a few chemical or outright forbiddance of the importattion, generation and utilization of specific substances, for example, or mercury-based pesticides, DDT and lead, may comprise the best way to ensure human wellbeing, the nature of waters and their oceanic verdure (counting fish for human utilization) and other particular water utilizes (ECLAC, 1989; UNECE, 1992; United Nations, 1994). Other water toxins that may end up becoming greatly lethal in high amounts as it may, are required in minute quantities. Phosphorus, manganese, zinc, copper and boron, for instance, can be poisonous or might some way or another unfavorably influence amphibian life when present above specific amounts, despite the fact that their presence in low quantities is crucial to bolster and keep up nature of oceanic biological communities. The same is valid for specific components for drinking water. Selenium, for instance, is good for the human body however it gets to be destructive or even poisonous when its levels surpasses a determined amount. The levels above which water poisons antagonistically influence a specific water use may contrast generally. Water quality standards, communicated as water quality criteria and goals, are use-specific or are focused to the security of the most vulnerable use of water among various existing or purposed uses around an area. Water pollutants can be grouped into various categories and these include the following;

i. Biodegradable waste which comprises for the most part of human and animal waste. At the point when biodegradable waste enters a water supply, the waste incorporates a vitality source (natural carbon) for microorganisms. Natural carbon is transformed into carbon dioxide and water, which can bring about air contamination and corrosive rain; this type of contamination is much more far reaching and hazardous than different types of poisons, for example, radioactive waste. On the chance that there is a vast supply of natural matter in the water, oxygen-expending (high-impact) microscopic organisms increase rapidly, devour all accessible oxygen, and destroy all amphibian life.

ii. Plant supplements, for example, phosphates and nitrates, enter the water through sewage, and animal and artificial manure overflow. Phosphates and nitrates are likewise found in mechanical wastes. In spite of the fact that these chemicals are regular, 80 percent of nitrates and 75 percent of phosphates in water are human-produced. At the point when there is a lot of nitrogen or phosphorus in a water supply (0.3 sections for each million for nitrogen and 0.01 sections for every million for phosphorus), green microbes growth start to proliferate. At the point when green growth increases tremendously, the water can turn green and overcast, look vile, and noxious. Weeds begin to develop and microscopic organisms spread. Breaking down plants use up the oxygen in the water, disturbing the amphibian life, diminishing biodiversity, and notwithstanding destroying sea life. This procedure, called eutrophication, is a characteristic procedure, yet for the most part happens over a large number of years. Eutrophication permits a lake to age and turn out to be more supplement rich; without supplement contamination, this may take 10,000 years, yet contamination can make the procedure happen 100 to 1,000 times quicker.

iii. Sediments standout amongst the most widely recognized origins of water contamination. Soil residue comprises of mineral or natural matter that is washed or blown from one area into water sources. Sediment contamination is hard to recognize, in light of the fact that it originates from non-point sources, for example, development, agricultural and domesticated animals operations, logging, flooding, and effluent spillover. Every year, water sources in the United States are dirtied by more than one billion tons of silt. Sediments can bring about substantial issues, as it can stop up civil water frameworks, destroy amphibian life, and cause water to be progressively turbid. Again, turbid water can bring about heat contamination, in light of the fact that turbid water takes in more of the Sun's radiation.

iv. Toxic and lethal chemicals are typically human-made materials that are not utilized or discarded legitimately. Point origins of such substance contamination include manufacturing effluents and oil spillage. Non-point origins of chemical contamination include spillover from under-construction streets and pesticide overflow.

v. Radioactive contaminants include wastewater releases from processing plants, health facilities and uranium extraction sites. These toxins can likewise originate from characteristic isotopes, for example, radon. Radioactive poisons can be perilous, and it may take numerous years until radioactive substances are no more regarded as unsafe (Oregon Department of Environmental Quality, 2004)

2.5 Overview of Access to Potable Water

Potable water is difficult to create provided all conceivable obstructions from the earth and artificial hindrances are present. Potable water does not contain pathogens, hazardous synthetic materials, and also, substances that are radioactive in nature, and it is free from foreign colour or scent. The rules for potable water quality indicate criteria points for materials that may be present and portray conditions that influence drinking water quality. The main cause of poor water quality is elicited by human impacts. Poor water quality is the reason why many people need filtration installation systems to be able to feel safe about their drinking water. Municipal water is deemed safe but still has chlorine and traces of heavy metals. Drinking plenty of water is important and for better health it is even more important that the water being drunk is purified water.

According to WHO (2004b), the number of people who did not have access to improved water supply in 2002 and those who endured water-related diseases caused by contamination were 1.1 billion and 2.3 billion, respectively. Each year, diarrhea-related diseases account for an average of 1.8 million lives with 90% of these deaths being children under five years (WHO, 2004b). Next to this, diseases that water-borne prevent people from living and working actively and sound.

All-important for the well-being of all people is thoroughly safe and potable drinking water quality. In Ghana, as well as many other like-countries around the world, some drinking water supplies have become fouled and this has struck the health and economic status of many nations (Akoto and Adiyah, 2007). Potable water has turned a scarce product due to pollution and over exploitation. Insufficiency and misapplication of water that is drinkable throw severe and growing threat to sustainable development and protection of the environment. The health of humans and their welfare, food security, industrial development and ecosystems are all at risk. Except when water and land resources are managed more effectively in the present time and beyond than they have been in the past (ICWE, 1992), these threats would remain major challenge.

Potable water is an indispensable treasured resource that is requisite for nourishing life. Water is a necessity in all facets of life. The main aim is to ensure there is sufficient supply of water of good quality to all people whiles preserving adequate amount9 and quality of water flow to sustain crucial functions of ecosystems (Bruntland, 1987). In various developing countries, the availability of potable water has become a critical and urgent problem and it is a matter of concern to the communities that depend on non-public water supply system.

Conformation with drinking water quality requirements is of exceptional interest because of its capability to spread infections within a large human population. Although the requirements vary from one setting to another, the goal anywhere is to decrease the possibility of spreading water borne diseases to the barest level in addition to being enjoyable to drink, which implies that it must be healthy and potable in all respects (Edema *et al.,* 2001).

2.6 Water Quality and Monitoring

Water quality checking is characterized as the inspecting and investigation of water conditions and components. They may comprise: effluent contamination, for example, metals, pesticides, and oil constituents if discovered actually in rivers may by and by be caused by anthropogenic sources, for example, dissolved oxygen, microscopic organisms, and supplements (DFID, 1999). The extent of their impact can be affected by properties for example temperature and pH. For instance, temperature affects the amount of dissolved diatomic oxygen that water can to carry, and pH influences the injuriousness of ammonia.

The nature of every river, stream or lake is determined by the amount of metal concentrated and physicochemical properties. The determination of physicochemical attributes of a river or stream is key for both long term impact and brief assessment of its quality (Tuzen *et al.*, 2002). Lakes, waterways and streams have critical multi – utilization segments, for example, they serve as the origins of potable water, plant watering system, fishery and power generation (Iscen *et al.*, 2008). Water is an uncommon and diminishing resource, and its management can have an impact on the stream and the nature of other water bodies (Prat and Munné, 2000). Growing human populace, industrial development, escalated rural activities and releases of huge measure of effluents into the waterways and streams have brought about decline of water quality (Herschy, 1999). Possible impact of these human activities has broad implications to the point that, to a vast degree the water bodies have lost their self-cleansing limit (Sood *et al.*, 2008). Lotic and lentic biological systems have been utilized for examination of components, regulating the conveyance and plenitude of oceanic living beings. The physical and synthetic attributes of water bodies influence the species abundance, plenitude, profitability and functional states of aquatic life forms (Bagenal, 1978).

2.7 Regulatory Standards for Drinking Water

With regards to the Safe Drinking Water Act (SDWA) of 1974, EPA provides legislation on limits concerning the amount of certain foreign materials in water for drinking. As far as possible mandatory frameworks reflect both levels that ensures human wellbeing and limits that water frameworks can accomplish utilizing the best accessible innovation. Other than recommending these legitimate breaking points, EPA principles set water evaluation calendars and strategies that water frameworks may take after. Tenets additionally list satisfactory methods for treating polluted water. The SDWA provides individual levels and limits the chance to set and uphold particular potable water measures provided the benchmarks are in any event as solid as EPA's national principles. A majority of states and regions specifically regulate the water frameworks inside of their fringes.

2.8 The National Water Policy

The country water approach of Ghana is planned to give a structure for manageable advancement of Ghana's water assets. This focuses on all water clients, water managers and specialists, speculators, leaders and policy managers within the focal Governmental and decentralized organizations, non-Governmental associations and international Agencies. This policy also identifies the different cross-sectorial matters associated with water use and the links to other relevant sectorial policies such as those on sanitation, agriculture, transport, energy etc. The national policy is structured into three sectors: Segment 1 introduces the diagram of the country's water division covering the condition of assets and administration foundations, advancement needs, universal commitments, expansive codes prompting initiative making. Section 2 determines the imperative approach issues joined with the fundamental standards and difficulties testing water assets administration change and use in the vegetation zones water assets administration, urban water supply, and communal water and sanitation. Segment 3 shapes recommendations and tenets for executing the approach including; zonal parts and obligations, models, regulations, descriptions and bibliography (National Water Policy, 2007)

2.9 Parameters used to assess Water Quality

The dramatic global industrialization, agricultural mechanization with modern agricultural practices, expansion of chemical industries and rapid development of cheap sources of energy variety had brought about stress on the ecosystem (Keller *et al.*, 2002, Quilbe *et al.*, 2004). The complexity and distribution of metals in the environment has changed continuously since their routine adoption into human society. A number of metals cobalt (Co), cupper (Cu), molybdenum (Mo), manganese (Mn), iron (Fe) and zinc (Zn) are vital micronutrients in green plants at very low concentrations (Spear, 1981, Scheinberg, 1991). Some of these metals (Cu, Zn) are potential toxins to many biological systems at elevated concentrations and some others (Pb, Cd) have no known physiological relevance at all concentrations except the detrimental health effects it produce on many living things (Amdur *et al.*, 1991, Abdus-Salam and Adekola, 2005). Pb, Zn, Cd, and Cu are common pollutants of the water environment. Their sources are essentially natural through geological modification (dissolution from earth crust, earthquake) or anthropogenic through atmospheric deposition, industrial and domestic sewage, run-off from mechanized agricultural field and chemical wastes discharged into bodies of water (Fatoki *et al.*, 2002, Olajire and Imeokparia, 2000). Water is an essential requirement of human and industrial developments and it is used directly or indirectly in many industrial processes in large quantities. Taking cognizance of the various processes and activities that could possibly influence the quality of water some specific parameters are measured to determine water quality and to ensure that certain use-specific standards are met to protect human health among others.

2.9.1 Physicochemical Parameters

There are quite a number of physical characteristics which are used to determine the quality of water to determine how fit it is for use in various domestic and industrial applications. Some of these parameters include:

2.9.1.1 Temperature

Natural and chemical processes occur at specific rates depending on temperature. Each and every marine animal, from microorganisms to fish are dependent on positive temperature ranges for their optimal wellbeing. For instance the best temperatures for survival of different species of fish: some endure best in Each and every marine animal, from microorganisms to fish are dependent on positive temperature ranges for their optimal wellbeing water with low temperatures, while some are inclined toward water with higher temperature. Small animals dwelling at the base of rivers are likewise delicate with regards to changes in temperature and will travel in the water column to locate ideal temperature (Amdur *et al.,* 1991, Abdus-Salam and Adekola, 2005). When temperatures are beyond this optimal range for an extended span of time, organisms could be under stress resulting in death. The temperature of water is measured in degrees Fahrenheit (F) or degrees Celsius (ºC) using a thermometer. Temperature impacts the measure of soluble oxygen in the water (oxygen levels get to be lower as temperature rises); the metabolic rates of benthic life forms; the rate of natural matter blend by marine plants; and the affectability of creatures to toxic substances, parasites, and maladies. Origins of temperature variation include evacuation of shading stream-bank vegetation, climate, impoundments (a waterway limited by a boundary, for example, a dam), urban water, release of cooling water and groundwater inflows to the riverine systems (Fatoki *et al.,* 2002).

2.9.1.2 The pH

The pH is a term used to specify the alkalinity or acidity of a substance and categorized on a scale from 1.0 to 14.0. Acidity increases as the pH gets lower. pH influences numerous substances and organic moieties in the water. For instance, diverse living beings thrive inside distinctive scopes of pH. A larger part of amphibian creatures favor a scope of 6.5-8.0. pH past this extent diminishes differing qualities in the water on the grounds that it troubles the physiological frameworks of most living beings and could bring about decreased propagation. Acidic water can likewise bring about lethal chemicals and compounds to be mobile and "bioavailable" for uptake by oceanic plants and creatures (Keller *et al.*, 2002, Quilbe *et al.*, 2004). This can elicit conditions that are destructive to marine life, particularly to fragile species like rainbow trout. Changes in pH can be brought on by the air quality (corrosive precipitation), presence of rocks, and certain effluent releases.

2.9.1.3 Turbidity

Turbidity which is a degree to which water is clear determines the amount of materials suspended in water diminish rays of light passing through water. Colloidal materials include sediment particles (earth, residue, and sand), green protoctists, plankton, microorganisms, and different materials. Such substances are ordinarily in the dimensions scope of 0.004 mm (mud) to 1.0 mm (sand). The amount of suspended matter in water can influence the nature of the water. Higher amounts of suspended matter increases water temperatures because suspended particles take up more thermal energy. The direct impact is reduction in the amount of dissolved oxygen (DO) owing to the fact that warm water dissolves less oxygen than cooler water. Increased turbidity in effect decreases the amount of light passing through the river, pond or stream, thereby reducing photosynthesis and the release of oxygen. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macro-invertebrates. Sources of turbidity include:

- Soil erosion
- Waste discharge
- Urban runoff
- Eroding stream banks
- Large numbers of bottom feeders (such as carp), which stir up bottom sediments
- Excessive algal growth.

2.9.1.4 Biological Oxygen Demand (BOD)

The riverine system synthetically forms and utilizes molecular oxygen. It picks up oxygen from the air and from plants as a consequence of photosynthesis. In lotic water system, in the light of its constant mixing, takes up more oxygen than lentic water system for instance, that in a dammed resource. Breathing by amphibian creatures, decay, and different reactions processes expend oxygen. Effluent from sewage treatment plants frequently contains natural materials that are disintegrated by microbes that make use of oxygen simultaneously. The measure of oxygen expended by these living beings in disintegrating the waste is known as the biochemical oxygen demand, simply known as BOD. Different wellsprings of oxygen-devouring waste incorporate storm-water overflow from farmland or urban boulevards, feedlots, and fizzling septic frameworks. The amount of oxygen is regarded in its soluble form in water as dissolved oxygen (DO). On the off chance that more oxygen is expended than is created, the amount of disintegrated oxygen reduce and some delicate creatures may move away, may be impaired, or death may ensue. The amount of dissolved oxygen vary regularly in a season and during the day. They change with water temperature and elevation from ground surface. Cooler water contain more oxygen than warmer waters, and amount of oxygen reduces with increasing elevation. Discharge from thermal systems, for example water used to cool machinery in an industrial plant or thermal plant raise the temperature of water and lower its oxygen content. Marine creatures are most defenseless against decreased dissolved oxygen levels in the early hours of summer days when river inflows are low. When lake or pond temperatures go high, algae therefore do not release oxygen until sunset.

2.9.1.5 Total Solids

Total solids are broken up solids notwithstanding the added presence suspended and colloidal particles in water. In stream water, broken down solids include chlorides, calcium, nitrate, phosphorus, sulfur, iron, and distinctive particles that will use a filter with pores of around 2 microns (0.002 cm) in size. Suspended materials include sediments and mud particulate matter, tiny fish, green algae, fine natural materials, and other particulate matter. These are particles that won't experience a 2-micron channel. The amount of aggregated colloidal particles influences the osmotic gradient in the cells of amphibian creatures. A living creature put in a river or stream with a low amount of particulate matter, for instance, treated water, will imbibe water and swell in light of the fact that water has a tendency to move into more concentration regions (cells), which have a higher amount of particulate matter. This will thus influence the living organism's capacity to keep up the correct cell density, making it hard to keep its position in the water section. It may suspend in or sink down to a profundity to which it is not adjusted, and it won't not survive. Higher amounts of suspended solids can serve as transporters of toxics, which easily adhere to suspended particles. This is especially worrying where pesticides are being utilized on irrigating food crops. In high suspended solid media, pesticide levels may build well past those of the first application as in the watering system water goes down irrigation trench. More elevated amounts of solids can likewise obstruct watering system gadgets and may turn out to be high to the point that flooded plant roots will lose water as opposed to pick up it (Akoto and Adiyah, 2007). An increased amount of suspended matter will render drinking water not potable or may elicit inimical impact on individuals not acquainted with drinking from such sources of water. The levels of total solids that are too high or too low can likewise decrease the proficiency of wastewater treatment plants, and in addition the operation of mechanical procedures that utilization crude water. Total solids additionally influence water clarity. Increased amount of solids diminish the light penetration in water, subsequently moderating photosynthesis by algae. Heating of water occurs more quickly and water retains more warmth; thus warming of water may antagonistically influence oceanic life that has adjusted to a lower temperature ranges. Industrial effluents, sewage, manures, street spillover, and soil disintegration are sources solids found in water. Total solids are measured in milligrams per liter (mg/L).

2.9.1.6 Anions /Cations

As forms of nitrogen containing compounds, nitrates is found in a number of forms in terrestrial and aquatic ecosystems. Ammonia (NH_3), nitrites (NO_2^-) and nitrates (NO_3^-) are forms of nitrogen occurring compounds. A nitrate is a salt of nitric acid with an ion composed of one nitrogen and three oxygen atoms (NO_3^-). Esters of nitric acid and various alcohols are also called nitrates. It is a naturally occurring compound that is formed in the soil when nitrogen and oxygen combine. It is highly soluble (dissolves easily) in water and relatively stable over a wide range of environmental circumstances. It is easily carried in streams, rivers and groundwater. Nitrate is a source of nutrient for plankton (microscopic plants and animals that live in water), aquatic plants, and algae, which are then eaten by fish.

A nitrite is a salt of nitrous acid (HNO_2). They are composed of a nitrite ion (NO_2^-). Nitrites of the alkali and alkaline earth metals can be produced by reacting a mixture of nitrogen monoxide (NO) and nitrogen dioxide (NO_2) with a corresponding metal hydroxide solution, and also by thermal decomposition of the corresponding nitrate. Other nitrites are available through the reaction of their corresponding nitrates. Nitrite is relatively short-lived in water because it is quickly converted by bacteria into nitrate. Nitrate is also broken down in animal or human intestine to nitrite; which has a higher toxicity than nitrate.

Small amounts of nitrate-nitrogen or nitrite-nitrogen (less than 10 mg/L or 1 mg/L respectively) in drinking water are normal however; excessive concentrations can be hazardous to health, especially for infants and pregnant women, nursing mothers, or elderly people causing a condition called methemoglobinemia. Nitrates are vital plant supplements, yet in abundance amounts they can bring about significant water quality issues. When combined with phosphates, nitrates in overabundant concentrations may quicken eutrophication, triggering growths in algae population and plant development and changes in the sorts of plants and creatures that thrive in the river or lake. Thus it influences temperature, dissolved oxygen and other water quality standards. Overabundance of nitrates can bring about hypoxia (low levels of dissolved oxygen) and could be dangerous to homoeothermic creatures at higher levels (10 mg/L) or higher) under specific conditions. The characteristic level of salts of ammonium or nitrate in surface water is regularly low (under 1 mg/L); in the wastewater treatment plants, it can range up to 30 mg/L. Wellsprings of nitrates include wastewater treatment plants, overflow from prepared gardens and farmland, defunct septic frameworks, spillover from organic fertilizer stockpiling regions, and modern releases that contain organic inhibitors.

Fluorine exists naturally in water sources and is derived from fluorine, which combines directly with carbon and even xenon, krypton and radon to form fluoride. The ubiquitous nature of fluoride is introduced into the body as an integral component of potable water and food. The gross ingestion of fluoride for adults is usually within the range of 0.2-2.0 mg of fluoride per day, although greater intake is also common (WHO 1984). Fluoride improves the precipitation of hydroxyapatite in substances containing calcium and phosphate (e.g., blood) and considerably it has a tendency to ameliorate the demineralization of bone and teeth. Fluoride acts on hydroxyapatite precipitates in bone and teeth, thus it has the capacity to counteract dental plaque and different bone demineralization issues, for example, osteoporosis and periodontal infection.

Fluoride may be present in very low concentrations in water usually ranging from less than 0.1 mg/L to more than 20 mg/L (WHO, 1984), but when it accumulates to higher concentrations it pose a potential health concern. Ingestion of excess fluoride in the drinking water is often found in rural, agriculture, sewage areas where it exceeds the drinking water limit of 40 mg per day and produces severe skeletal deformity. Common sources of high fluoride occur during weathering where circulation of water in rocks and soils leached fluorine out into ground water.

Sulphates occur in most natural water in wide range of concentration. High values of sulphate above 200 mg/l can lead to attack of diarrhoea especially in new comers to the high sulphate water supply. In groundwater, the majority of sulfates are created from the disintegration of minerals, for example, gypsum and anhydrite. Introduction of salty water and corrosive rock seepage are additional wellsprings of sulfates in drinking water. Man-made sources incorporate industrial effluents and effluents from combustion of fossil powers. Measuring sulfate concentrations in water is a regarded chemical procedure. Despite the fact that sulfate does not represent a wellbeing danger at levels ordinarily found in drinking water, its manifestation in water can demonstrate depreciation in groundwater quality which could exhibit different complications in terms of water quality, arousing unfavorable wellbeing impacts. The major physiological impacts arising from the ingestion of huge amounts of sulfate are catarrh, diarrhoea, and gastrointestinal discomfort.

2.9.1.7 Heavy Metals

Heavy metal is term applied to metals with an atomic density above 5 g/cm3 (Walker and Sibly, 2001). Heavy metals that are essential in environmental and body health include iron, cadmium, arsenic, lead, nickel, copper, mercury, zinc, cobalt, tin, chromium and vanadium (WHO, 1996). Although some are required by living organisms in trace amounts eg. iron and zinc, excess levels are detrimental. The non-essential heavy metals eg. arsenic, lead and mercury are generally poisonous since they affect some metabolic and biological processes.

Arsenic (As)

Arsenic is a naturally abundant metalloid originating from the earth's crust. Arsenic occurs naturally in the mineral mispickel or arsenopyrites. Low levels of arsenic are likewise present in plants and animals, for example, fish and also in the atmosphere. It is ordinarily found in a blend with different components forming arsenic compounds and has no unique taste or smell. A significant number of these compounds are actually found in nature but some are man-made. When arsenic occurs at low levels, there is moderately little to worry about. A great number of people take in little concentrations of arsenic in the food material they ingest, however drinking water with low to average levels of arsenic can give more than is required. The most poisonous type of arsenic, known as inorganic arsenic, is the nature ordinarily found in groundwater. Inorganic As compounds are classified as carcinogenic to humans (Asklund and Eldvall, 2005).

Studies have demonstrated that individuals drinking well water with increased levels of arsenic have higher potential of contracting some ailments. Drinking great water with low to tolerably increased levels of arsenic over a period of time may prompt constant wellbeing impacts. Serious wellbeing impacts, for example, tumor, are created over some years and can be hard to identify, particularly in the early stages. Elevated levels of arsenic can also induce immediate or acute health effects that typically have more perceptible symptoms.

The level of Arsenic in natural waters generally ranges between 1 and 2 mg/l, (Asklund and Eldvall, 2005). Concentrations of arsenic may be elevated, however, in areas containing natural sources; values as high as 12 mg/l have been reported. As is a component in the manufacture of bronze materials, fireworks, agricultural chemicals, laser materials, glass, semiconductor materials, wood preservatives, copper and lead alloys and insecticides (Hardy *et al.*, 2008).

Copper (Cu)

Copper occurs in soil, rocks, water, plants, air and other living things. It is a component in metal alloys, electrical wiring, some water tubes, preservatives for wood, animal skin and fabrics, and some horticultural fungicides, (Hardy *et al.*, 2008). Cu is a key plant micronutrient. Nonetheless, at abnormal concentrations, it might be lethal to plants.

It can also bind to soil organic matter and become unavailable to plants. Higher availability is usually associated with low pH. Copper is a crucial nutrient supplement that the body requires in little amounts. In any case, drinking elevated amounts of copper can bring about sickness, regurgitating and loose bowels, and can harm your liver and kidneys

Iron (Fe)

Iron is an important element in human nutrition. The most common sources of iron in groundwater are naturally occurring, for example from weathering of iron bearing minerals and rocks. Industrial effluent, acid-mine drainage, sewage and landfill leachate may also contribute iron to local groundwater. Assessments of the minimum daily prerequisite for iron depend on age, physiological status, sex and iron bioavailability and ranges from about

10 to 50 mg/day (Asklund and Eldvall, 2005). Fe (II) salts are unstable and are precipitated as insoluble Fe (III) hydroxide in drinking water which settles out as a rust-coloured silt. Anaerobic groundwater may contain Fe (II) in amounts up to a few milligrams for every liter without discoloration or turbidity in the water when straightforwardly pumped from a well. Turbidity and discoloration may create in channeled frameworks at Fe levels above 0.05-0.1 mg/l, while levels of 0.3-3 mg/l are normally discovered satisfactory.

2.9.2 Biological indicators

Coliform bacteria are defined and grouped based on their collective origin or characteristics, as either Total or Faecal Coliform. The total coliform group includes faecal Coliform bacteria such as *Escherichia coli (E.coli)*, together with other types of Coliform bacteria that are normally found in the soil. Faecal Coliform bacteria are known to be present in the intestines of homoeothermic animals including humans, and are found in excreta, animal droppings and naturally in soil. Most of the Faecal Coliform in faecal material (faeces) comprise of *E.coli*, and the serotype *E.coli* 0157:H7 is known to cause serious human illness.

Coliforms and fecal streptococci, are used as indicators of probable sewage pollution because they are normally found in human and animal feces. Though they are usually not harmful themselves, they point to the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Their presence in water therefore suggests that pathogenic bacteria might also be present and might be a health risk. Since it is challenging, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and faecal streptococci instead. Sources of faecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff (Akoto and Adiyah, 2007). In addition to the probable health risk accompanying the presence of increased levels of faecal bacteria, they can also cause cloudiness water, unfriendly odors, and an increased biochemical oxygen demand.

The most frequently tested faecal bacteria indicators are total coliforms, faecal coliforms, *Escherichia coli*, faecal streptococci, and enterococci. All but *E. coli* are composed of a number of species of bacteria that share mutual characteristics such as shape, habitat or behavior; *E. coli* is a single species in the faecal coliform group (ICWE, 1992).

Total coliforms are an assemblage of microorganisms that are rife in nature. All individuals from this assemblage can be found in human dung, however some can likewise be available in animal excrement, soil, and submerged wood and in different spots outside the human body (Zeb *et al.*, 2011). Thus, the practicality of total coliforms as an indicator of faecal pollution depends on the degree to which the bacteria species occuring are faecal and human in origin. For public recreational waters, total coliforms are no longer endorsed as an indicator. For drinking water, total coliforms are still the standard test on the grounds that their presence shows pollution of a water supply by an outside source (Yerel, 2009).

Faecal coliforms, a smaller cluster of total coliform bacteria are usually fecal-specific in origin. On the other hand, even this cluster contains a variety, *Klebsiella*, with animal types that are not as a matter of course fecal in origin. *Klebsiella* are usually connected with clothing and pulp and paper factory wastes. Consequently, if these sources are released to a particular stream, it may be better to consider checking regularly the fecal and human-specific microorganisms. For recreational waters, the cluster of microbes was the essential pollution pointer until of late, when EPA started suggesting *E. coli* and enterococci as better pointers of pathogenic hazards from water contact. Fecal coliforms are as yet being utilized as a part of the indicators in numerous states for determination of microbial or faecal contamination (Yerel, 2009).

E. coli is a group of faecal coliform bacteria which is particular to faecal material from humans and other homoeothermic organisms. The environmental agencies endorse *E. coli* as the paramount indicator of health hazard from water contact in recreational waters; some states have altered their water quality criteria and are thus monitoring subsequently (Zeb *et al.,* 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The Amansie Central District of the Ashanti region was the study area. Jacobu is the administrative capital of this district. There are twenty-seven (27) administrative districts in the Ashanti Region, it found in the forest plateau area of the Ashanti region with altitudes ranging from 150 m and 300 m above sea level. The catchment of this area is about 300 sq. km and is relatively flat. The semi equatorial and wet climates occur in this area and there is much rainfall the rainy season which begins in April until June and continues from September to November. The annual rainfall ranges from 1600mm – 1800mm. Temperatures range between 20°C and 32°C. The month of August records the lowest temperatures whereas the dry season months of March and April record the highest. The district falls largely within the moist semi-deciduous forest vegetation zone which contains a lot of the valuable timber species as well as tree crops such as cocoa and citrus. The district is underlain by three geological formations; the Birimian, Tarkwaian and Granite rocks which are rich in mineral deposits (Survey Department of Ghana, 1977).

Close to the north of the capital Jacobu within the district are the Aboabo and Pataase communities were the study was conducted (Fig. 1). These are predominantly farming communities through which runs the Aboabo stream (Survey department of Ghana 1977).

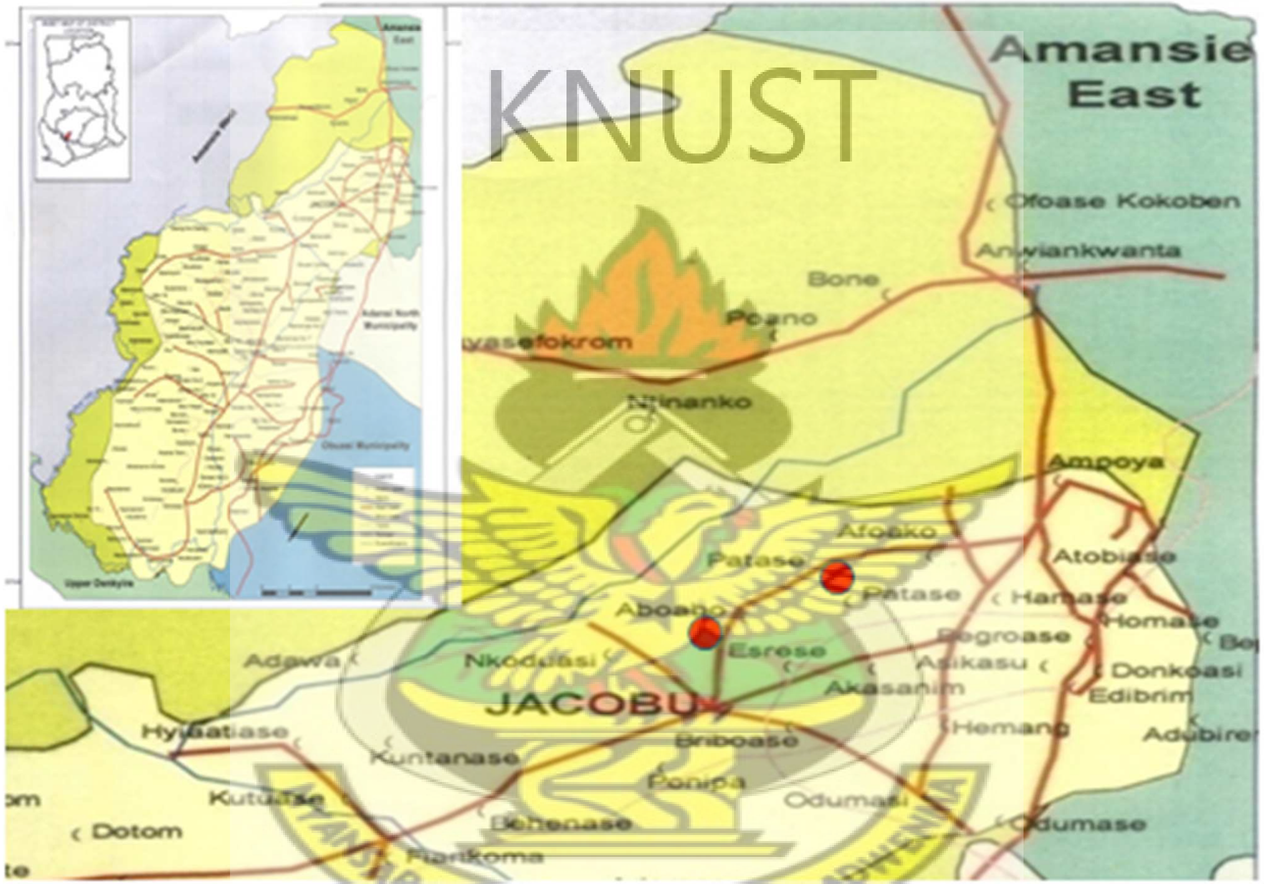


Figure 2: Location Map of the Amansie Central District showing the Aboabo and Pataase communities; Inset is the Map of Ghana and the Amansie Central District in the Ashanti Region.

3.2 Selection of Sampling sites.

Sampling was carried out in Aboabo and Pataase, on the outskirts of Jacobu, the capital of the Amansie Central District. The communities were selected based on their reliance on the Aboabo stream until it got polluted by mining activities.

3.2.1 Sampling of Water Sources

Following an initial survey, all groundwater sources utilized by inhabitants of the Aboabo and Pataase communities at the time of the study were chosen. The Aboabo stream on which the inhabitants used to depend on has been heavily polluted. The sampled water sources consisted of two bore holes labeled BHA 1 and BHA 2, and a well (WA 1) within the Aboabo community as well as two bore holes (BHP 1 and BHP 2) and two hand-dug wells (WP 1 and WP 2) at Patase (Plate1-4).

3.2.2 Sampling of Household Water

The households were selected based on their willingness to participate after the study had been explained to them. The systematic random sampling was used, where every fifth house from a first house selected randomly along the main street was visited. If inhabitants of a household were absent or refused participation, the next house was considered and the process continued counting from the non-respondent house (Welch *et al.*, 2000).

3.3 Water sampling

3.3.1 Preparation of Sampling containers

Water samples were collected into 750 ml plastic bottles. Before sampling was conducted, the sampling bottles were washed using warm water and detergent, rinsed with deionised distilled water after which dilute nitric acid solution was used to wash them, and then rinsed again with deionised water and dried in a drying cabinet. To ensure the bottles were ready for use with minimal contamination, a sample of bottles were selected, filled with distilled water and the pH tested. A neutral pH indicated the bottles were ready for use (Anon, 1992).

3.3.2 Collection of Water Samples

At the sampling point, water from the borehole was pumped out for a while, after which the appropriate pre-labelled sampling bottles were each rinsed thrice before being directly filled to capacity (without air space) and immediately covered. The water from the well was collected using a plastic container with a rope attached to it (Obiri- Danso *et al.*, 2010). The pre-labelled sampling bottles were in each case rinsed thrice before being filled to capacity and covered immediately. The samples for further analysis were immediately stored on ice and immediately conveyed for analysis in the Laboratory. For the collection of household water, water purposefully requested for drinking was transferred into pre-labelled sterile bottles for microbial analysis.

Duplicate samples were taken during the early hours of the morning, once every month over a period of six months (from December, 2013 to May, 2014). Households were visited between 3.00 pm to 6.00 pm when most of the residents were home. For those responsible for collection of water, questionnaires were administered to solicit for information relating to household characteristics, main source of drinking water and water storage.

Plate 1: A functional Borehole in the Patase community

Plate 2: A functional Borehole in the Aboabo community

Plate 3: A Hand-dug well in the Pataase community

Plate 4: A Hand-dug well in the Aboabo community

3.4 Laboratory Analyses

3.4.1 Measurement of some Physicochemical parameters - Temperature, pH, Salinity, Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Dissolved Oxygen (DO).

A portable HANNA (HI 9828) multi-parameter Probe (pH/ORP, Conductivity, D.O.) water quality checker was used to determine the total dissolved solids (TDS), salinity, temperature, electrical conductivity (EC), pH and dissolved oxygen (DO) of samples on-site. Featuring a control unit with an LCD display and a powerful integrated multi-sensor probe, the instrument is designed for easy use on-site and provides reliable water quality data by immersing the sensor in the water. Up to 12 parameters can be enabled and seen simultaneously on the large graphic display.

The instrument was first calibrated using the HI 9828-25 quick calibration standard solution. On the field, after collecting some the water sample into a plastic container, the probe was rinsed with deionized water and immediately immersed into the collected water sample. The digital readings were then allowed to stabilize and the respective values recorded after which the sensors were thoroughly rinsed with deionized water before the next water sample measurements.

3.4.2 Colour

The colour of the water samples were determined by the Platinum- Cobalt method using the Wagtech Potalab photometer 7100 series (using an advanced solid-state digital readout colorimeter) which had already been calibrated with coloured standards of known platinum cobalt concentrations. In order to measure the true colour, the water sample was first filtered through a filter paper to remove interferences due to turbidity. The cuvette was rinsed with distilled water and then filled to the 10 ml mark with distilled water after which it was inserted into the photometer chamber and blanked. The cuvette was then removed, the content discarded, rinsed with some of the filtered water sample and filled with the filtered water sample to the 10 ml mark. The cuvette was then inserted into the sample compartment whiles ensuring that the sides were clean, the colour mode was selected from the testing menu and the reading recorded in colour units (CU).

3.4.3 Turbidity

Turbidity values were recorded in Nephelometric Turbidity Units (NTU) using the Wagtech Potalab photometer 7100 series after the turbidometer had been calibrated following manufacturer's instructions. The cuvette was rinsed thrice with the water sample to be tested after which it was filled with 10 ml of the sample and then inserted into the optical chamber of photometer. The turbidity mode (PHOT 48) was then selected on the photometer and the displayed turbidity reading was recorded.

3.4.4 Determination of BOD

Airtight BOD bottles were filled with the sample and distilled water to the brim. The samples were plugged with cork and kept in a dark incubator at 20°C for five days. The amount of dissolved oxygen was measured prior to (initial) and post (final) incubation for five days. BOD was calculated as the difference between the first and final dissolved oxygen amounts (APHA, 1992).

3.4.5 Determination of COD

Into a vial containing 2.4 ml of the sample (test sample) was added 1.5 ml of potassium dichromate reagent and 3.5 ml of sulphuric acid. The vial was closed and kept at 150°C for 2 hours in a digester. The sample was titrated against ferrous ammonium sulphate solution using ferroin as indicator after it was allowed cool to 25°C. Development of reddish brown colour was end point (APHA, 1992). The procedure was repeated using distilled water which served as the blank sample.

The COD was then calculated using the formular;

$$\text{COD} = \frac{(\mathbf{A-B})*\mathbf{M}*\mathbf{8}*\mathbf{1000}}{\mathbf{V}}$$

Where,

A = concentration of ferrous ammonium sulphate for blank sample,

B = concentration of ferrous ammonium sulphate for test sample,

M = Molar concentration of ferrous ammonium sulphate

V = volume of test sample used

3.4.6 Alkalinity

Alkalinity was determined using the titration method by titrating a water sample with sulphuric acid. Briefly three drops of phenolphthalein indicator was added to 100 ml of the water sample in a conical flask and titrated with 0.02N of H_2S0_4.

Alkalinity of water was determined by the fomular below;

$$\text{Alkalinity as in mg/L CaCO3} = \frac{\mathbf{V*N*1000}}{\mathbf{Vol.of\ sample\ (ml)*2}} * \mathbf{100}$$

Where;

V = titration volume in ml

N = Normality of acid solution

100 = molecular mass of CaCO3

3.4.7 Total Hardness

Total hardness was determined using the Wagtech Potalab photometer 7100 series. Following the Palintest method, fifty millilitres of the sample was filtered using a filter paper to obtain a clear sample of water after which 10ml of the filtered sample was put into a beaker. One Hardicol No 1 tablet (containing lithium hydroxide monohydrate, potassium chloride, EDTA, magnesium, disodium salt, leucine and ammonium chloride) was crushed and mixed with the sample in a test tube, allowed to dissolve and then one Hardicol No 2 tablet (containing sodium hydroxide) was also crushed and added with the sample to dissolve. The sample was allowed to stand for about 30 minutes until the particles were completely dissolved to produce a purple colour. A wavelength of 570nm was selected on the photometer and readings recorded from the LCD screen.

3.4.7.1 Determination of Calcium (Ca) Hardness

Into a 250 ml conical flask was pipetted 100 ml of the water sample. Four millilitres of 1N sodium hydroxide solution was added to the contents of the flask to increase the pH to about 12 or 13 followed by the addition of about 0.2g murexide indicator mixture. The content in the conical flask was titrated against 0.02M EDTA to the end point; indicated by a change in colour from pink colouration to purple. Titration was repeated until a consistent titre was obtained (APHA, 1998).

Calculation: Calcium Hardness as CaCO3 (mg/L) = **A** × **B** × 1000/ ml of water sample

where;

A = ml titrant for sample and

B = mg $CaCO_3$ equivalent to 1.00 mL EDTA titrant at the calcium indicator end point.

3.4.7.2 Determination of Magnesium (Mg) Hardness

The Magnesium hardness of the water sample was calculated as the difference between the total hardness and Calcium hardness values obtained from analysis of the sample.

3.4.8 Determination of Sulphate (SO_4^{2-})

The Wagtech photometer was initially calibrated for the measurement of sulphate, using standards provided by the manufacturer and following manufacturer's instructions. One Sulphate turb tablet (containing Barium Chloride in a slightly acidic formulation) was crushed and mixed in a test tube with about 10 ml of the filtered water sample and allowed to dissolve. A cloudy solution indicates the presence of sulphates. The solution was allowed to stand for 5 minutes and then mixed again to ensure uniformity. A wavelength of 520nm was selected on a Wagtech photometer and the concentration of sulphate in samples recorded.

3.4.9 Determination of Nitrites (NO_2^-)

Using calibration standards provided by the manufacturer, the photometer was calibrated following manufacturer's instructions. About 50 ml of the water sample to be tested was filtered with a Whatman 1 filter paper to obtain a clear solution. A pipette was used to take 1ml of the filtered sample and transferred into a test tube and made up to 10 ml with distilled water. One Nitrophot No.1 tablet was crushed and mixed with the sample to dissolve followed by the addition of one crushed Nitrophot No 2 tablet to the sample solution to dissolve. The test tube was capped immediately and allowed to stand for exactly 2 minutes for full colour development. A wavelength of 570 nm was selected on the photometer and the readings were then taken.

3.4.10 Determination of Nitrates (NO_3^-)

A Nitratest tube was filled with 20ml of the water sample. One nitratest tablet was added to a spoonful of nitratest powder. The test tube was capped and shaken well for 1 minute. The sample was left for two minutes to settle down and carefully inverted three or four times to aid flocculation and then allowed to stand for a further two minutes to ensure complete settlement. The cap was then removed and the mouth wiped with a clean tissue. About 10 ml of the clear solution was then decanted into another test tube. One nitrocol tablet was crushed and mixed to dissolve and this was allowed to settle for few minutes for full colour development and inserted into the sample chamber of the photometer. A wavelength was adjusted to 570 nm as specified on the photometer for the determination of nitrates and the readings taken.

3.4.11 Determination of the levels of Iron

A clean test tube was filled with about 10 ml of the water sample. One tablet of iron High Range tablet was crushed and mixed with the water sample and allowed to dissolve in the water. This was allowed to stand for one minute for full colour development. A wavelength of 570 nm was selected on the photometer as specified by the manufacturers' instruction for the determination of iron and readings taken directly.

3.4.12 Determination of Fluoride (F^-)

The water sample (10ml) with transferred into clean test tubes. One fluoride No.1 tablet was crushed and mixed with the sample to dissolve after which another tablet (fluoride No. 2) was also crushed and mixed with the sample to dissolve. The solution was allowed to settle for a short time until full colour developed. A photometer with selected wavelength of 570nm was used to read fluoride concentrations.

3.4.13 Determination of Chloride (Cl^-)

The amount of chloride in the water sample was calculated using the Argentometric method (APHA, 1992). In this procedure, 1.0 ml K_2CrO_4 indicator solution was added to 20 ml of sample water in a conical flask. The solution was titrated with standard $AgNO_3$ solution to obtain a pinkish yellow end point. About 20 ml of distilled water was used as the blank sample, the procedure is repeated, after which the concentration of chloride was calculated using the equation below;

$$\mathbf{mg\ Cl^{-}/L = \frac{(A - B) \times N \times 35450}{Vol.\ of\ sample}}$$

Where:

A = ml titration for sample,

B = ml titration for blank, and

N = normality of $AgNO_3$ (0.0141M)

3.4.14 Determination of Total and Faecal coliforms

The water sample was thoroughly mixed by inverting the sample bottle several times and serial dilutions prepared as follows: Using an automatic pipette and sterile 1 ml pipette tip, a 1 ml aliquot from an inch below the surface was taken and added to 9 ml of sterile ringers solution (diluent) in a test tube, making the 10^{-1} dilution. Again, a fresh sterile pipette tip was taken and the 10^{-1} dilution mixed by drawing the suspension up and down 10 times. 1 ml of the 10^{-1} level concentration was pipetted into another tube filled with 9 ml of sterile ringers solution, making the 10^{-2} dilution. Subsequent dilutions; 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} were prepared by repeating the above procedure further five times.

3.4.14.1 Total / Faecal coliforms

The determination of total and faecal coliforms numbers in samples was done using the Most Probable Number (MPN) method. Serial dilutions ranging from 10^{-1} to 10^{-7} were ready made ready by mixing 9 ml sterile distilled water with 1 ml of the water sample. One milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth and incubated for 35^{0}C for total coliforms and 44^{0}C for faecal coliforms for 18-24 hours. Tubes with colour changing from purple to yellow were recognized as positive for both total and faecal coliforms. Counts per 100 ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.4.14.2 *E. Coli* (Thermotolerant coliforms)

Identification of the presence of *E. coli* in the water samples was done using the Most Probable Number (MNP). A drop of positive samples was put into a 5 ml test tube containing trypton water and kept at 44^{O} C in an incubator for 24 hours. About 1 ml of Kovacs' reagent was then added to the test tube containing trypton water. Test tubes showing a red ring colouration that develops after mild shaking indicates the manifestation of indole verifying the presence of themotolerant coliforms which includes (*E. coli*). Microbial counts per 100 ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.5 Statistical analysis of data

Data was analysed using Microsoft Excel (2010 edition) for the descriptive analysis and graphs and the Statistical Package for Social Science (SPSS- version 19) using the Analysis of Variance (ANOVA) was used to determine the differences in the mean values of the parameters at the various sampling sites.

CHAPTER FOUR

RESULTS

4.1 Physicochemical parameters

4.1.1 Temperature, pH, Colour and Conductivity

The temperatures of all the water samples were found to be normal. Highest mean temperature of water was recorded in WP2 (27.30 ± 0.66 ºC). Intermediary mean temperatures were noted for WA1 (27.02 ºC), WP1 (26.90 ºC), BHA1 (26.66 ºC), BHA2 (26.64 ºC), and BHP2 (26.50 ºC) with BHP1 (26.34± 0.43 ºC) recording the least (Table 2).

Water from BHP1 (6.34 ± 0.49) had the highest pH. BHP2 followed with a pH of 6.28 ± 0.42. Water from WP2 (5.80 ± 0.29) recorded the least pH [Table 2]. All mean pH values were slightly acidic.

Appearances of water colour were strong in water samples from the wells than water from the boreholes. WP1 had the highest colour of 21.29 (± 0.17) CU and the minimum value recorded was for the water from BHP1 (1.03 ± 0.08) CU [Table 2].

Water from WP2 (581.22 ± 0.41) had the highest conductivity. WP1 followed with conductance of 393.00 ± 3.30 and BHA1 (379.00 ± 3.80). Water from BHP2and BHA2 had an equal conductivity of 68.36 which was the least conductivity recorded. (Table 2). Differences in conductivity between most water sources were significant ($p < 0.0001$).

Table 2: Mean values of some physicochemical parameters

Water source	Temperature (º C)	pH	Colour (CU)	Conductivity (µS/cm)
BHA1	26.66 (± 0.73)	6.00 (± 0.36)	6.38 (± 0.73)	379.00 (± 3.80)
BHA2	26.64 (±0.24)	5.94 (± 0.64)	6.40 (± 0.68)	68.36 (± 0.48)
WA1	27.02 (± 0.74)	5.94 (± 0.29)	15.40 (± 1.32)	130.56 (± 10.0)
BHP1	26.34 (± 0.43)	6.34 (± 0.49)	1.03 (± 0.08)	174.75 (± 0.70)
BHP2	26.50 (± 0.35)	6.28 (± 0.42)	5.00 (± 0.31)	68.36 (± 0.40)
WP1	26.90 (± 0.64)	5.88 (± 0.38)	21.29 (± 0.17)	393.00 (± 3.3)
WP2	27.30 (± 0.66)	5.80 (± 0.29)	20.10 (± 0.40)	581.22 (± 0.41)
WHO STANDARD	--	**6.5 – 8.5**	**15**	**1500**

4.1.2 Total Dissolved Solids

The mean levels of Total dissolved solids in water from the different water sources are shown in Figure 3. The levels of the Total dissolved solids from the various sources were all below the WHO limit of 1000 mg/L. Water from WP1 (308.80 mg/L) had the highest mean Total Dissolved Solids. This was followed by BHA1 (236.00 mg/L), WA1 (124.35 mg/L), WP2 (118.42 mg/L), BHP1 (105.30 mg/L), and BHP2 (40.84 mg/L) in decreasing order, whilst BHA2 (40.36 mg/L) recorded the least mean TDS. Generally differences in levels of TDS of the different water samples were significant at $p \leq 0.05$.

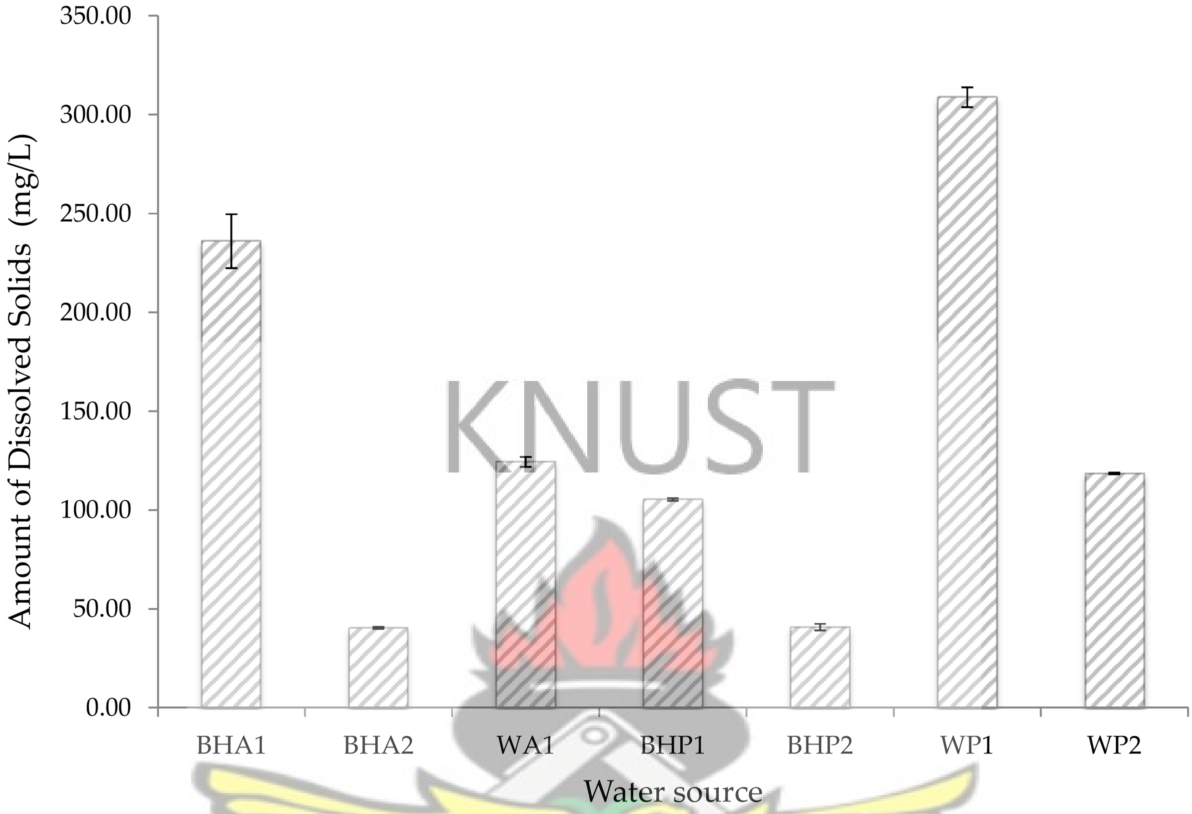


Figure 3: Mean amount of Total Dissolved Solids in different water sources

4.1.3 Salinity

The mean amounts of salt present in the water from various sources were generally within the permissible limits of the WHO with the exception of WP2 (1020.00 mg/L) which recorded the highest salinity. Water from BHP2 (450.00 mg/L) recorded the least. (Figure 4).

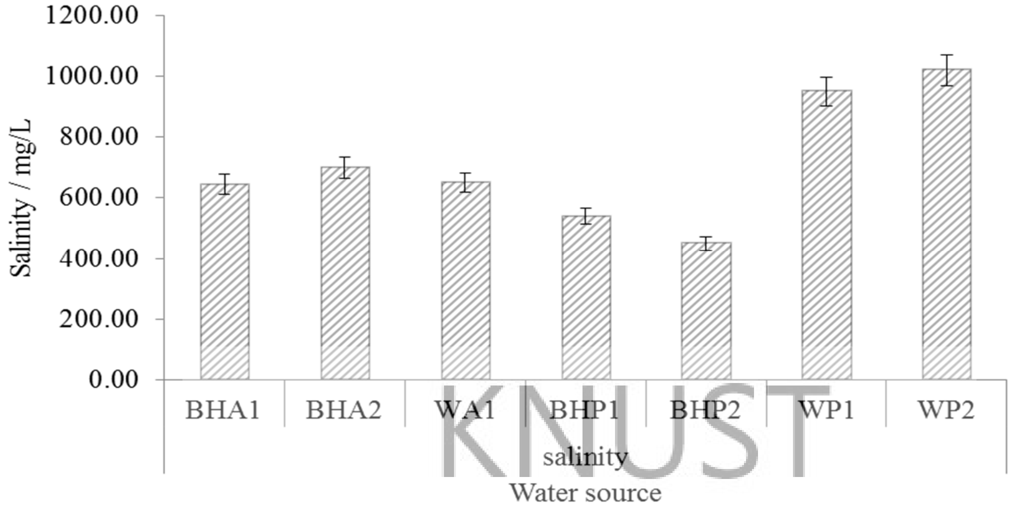


Figure 4: Mean salinity of water from the different sources

4.1.4 Turbidity

Turbidity of water samples in the study communities ranged from a mean value of 0.06 – 3.22 NTU for boreholes and 1.77 – 5.05 NTU for Hand-dug wells. The highest mean turbidity level of the water was recorded in WA1 (5.02 NTU). WP1 had (4.13 NTU), BHP1 (3.22 NTU), BHA1 (1.90 NTU), WP2 (1.77 NTU) followed respectively. BHP2 had the lowest turbidity level of 0.06 NTU (Figure 5).

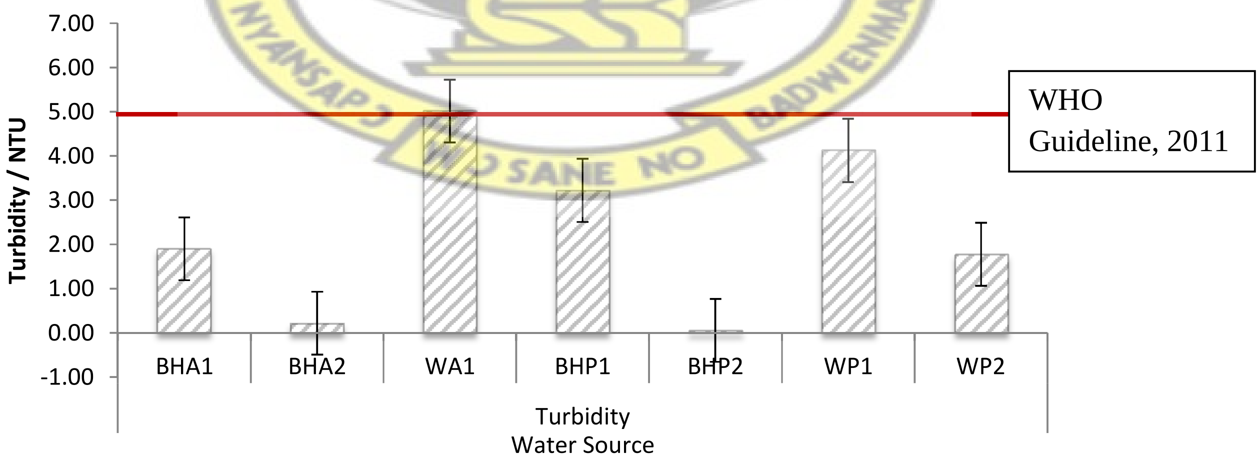


Figure 5: Mean turbidity of water from different water sources

4.1.5 Total Alkalinity

Maen Total alkalinity of water ranged from 16.60 mg/L to 55.00 mg/L in the water from various sources. The highest alkaline level was recorded in water from WP2 (55.00 mg/L). The level of alkalinity recorded for the other water sources in this study in decreasing order was BHP1 (42.26 mg/L), WA1 (31.00 mg/L), BHA2 (20.20 mg/L) and BHA1 (16.60 mg/L) respectively (Figure 6). Alkalinity of water from all the sources were below the WHO standard of ≤ 200 mg/L

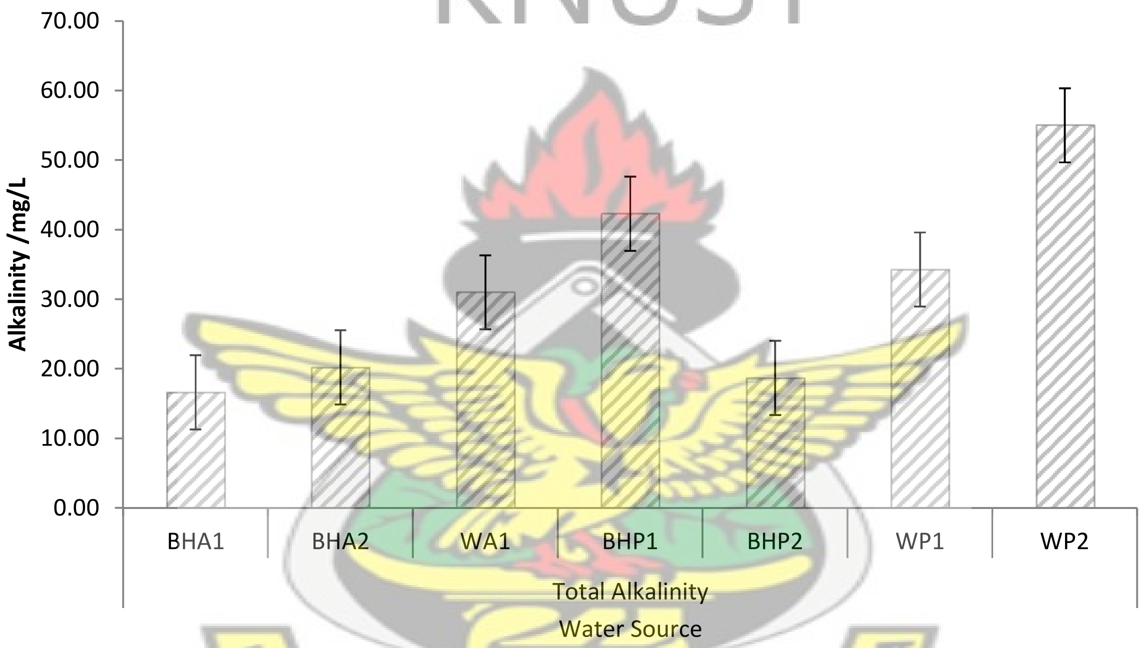


Figure 6: Mean Total Alkalinity of different water source

4.1.6 Amount of Oxygen

Figure 7 shows the amount of oxygen in water from the different sources considered in this study. The amount of Dissolved Oxygen recorded was highest in water from BHA2 (3.54 mg/L). The Dissolved Oxygen content recorded in water from the various sources were; BHP1 (3.51 mg/L), BHP2 (3.49 mg/L), WA1 (3.47 mg/L), WP1 (3.00 mg/L), WP2 (3.00 mg/L), and BHA1 (2.62 mg/L).

Water from BHP1 had the highest chemical oxygen demand of 1.11 followed by BHA2 (1.06 mg/L), WA1 (0.98 mg/L), BHP2 (0.94 mg/L), WP1 (0.72 mg/L) and BHA1 (0.48 mg/L) [Figure 7].

High biological oxygen demand was recorded in water from BHP1 (0.73 mg/L). BOD value of water from BHP1 was followed by different demands of Biological Oxygen in water from BHA2 (0.53 mg/L) through BHP2 (0.47 mg/L), WA1 (0.40 mg/L), WP1 (0.37 mg/L) and BHA1 (0.26 mg/L) to WP2 (0.19 mg/L).

Individual water sources had varying amounts of the different forms of Oxygen demand available to the Biota. All the different sources had Dissolved Oxygen the highest, followed by the chemical Oxygen demand and the Biological Oxygen demand the least. (Figure 7)

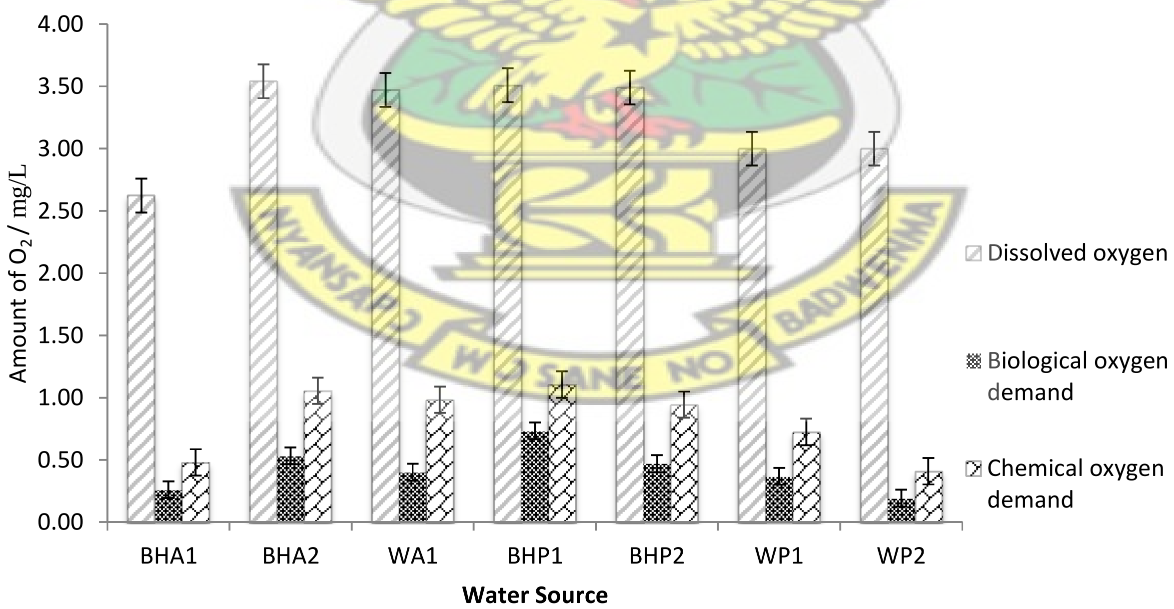


Figure 7: Mean amount of Oxygen demand

4.1.7 Total Hardness of water

Water from BHA1 had the highest (70.99 mg/L) Total whist water from BHA2 (34.20 mg/L), recorded the least total hardness (Figure 8)

Water from BHA1 again had the highest calcium hardness of 60.60 mg/L of water followed by calcium hardness of WP1 (34.20 mg/L), BHP1 (33.20 mg/L), WP2 (23.50 mg/L), WA1 (21.00 mg/L).Water from BHA2 (9.20 mg/L) and BHP2 (9.20 mg/L) had an equal degree of hardness caused by calcium were the least recorded (Figure 8).

Water hardness caused to a larger extent by magnesium was found in water from BHP2 (25.84 mg/L) and BHA2 (25.00 mg/L). Hardness of water attributable to magnesium in water from the other sources studied were WA1 (20.80 mg/L), WP2 (20.06 mg/L), BHP1 (12.19 mg/L), BHA1 (10.39 mg/L) and WP1 (8.29 mg/L) [Figure 8]. Water from all the sources were below the WHO limit of 500 mg/L $CaCO_3$.

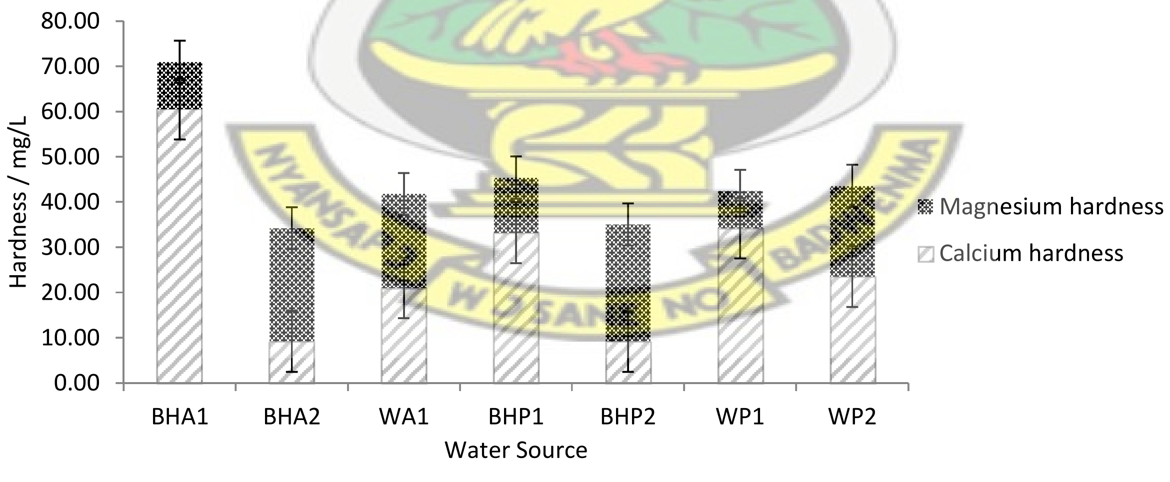


Figure 8: Mean hardness of water from different source

4.1.8 Concentration of Anions

There was varying amount of minerals in almost all the different source of the water. The mean chloride content of water from the various sources ranged from 12.51 mg/L to 17.76 mg/L, all of which were within the permissible limit of the WHO guideline value of ≤ 250 mg/L drinking water. Water from WP2 (17.76 mg/L) was noted as having the highest amount of chloride during the study period. Chloride content of water from BHP2 (15.60 mg/L) was next followed by BHA2 (15.40 mg/L) while WP1 (12.51 mg/L) recorded the least chloride content (Table 3).

Water from BHA1 (1.80 mg/L) had the highest fluoride followed by that recorded in WP1 (1.70 mg/L), WP2 (1.64 mg/L) BHP1 (1.35 mg/L), WA1 (0.61 mg/L), BHP2 (0.44 mg/L) respectively. Water from BHA2 was noted as having the least fluoride content of 0.42 mg/L (Table 3). Differences in mean fluoride content of water from the different sources were significant at $p \leq 0.05$.

The amount of Sulphate in water was highest in water from WP1. Water from WP2 recorded the highest Nitrate and BHP2 was noted for high Nitrite levels (Table 3). Levels of sulphate were all within the WHO guideline value of 250 mg/L.

Water from WP1 (13.14 mg/L) had the highest amount of Sulphate followed by WA1 (10.39 mg/L), BHA1 (5.40 mg/L), WP2 (4.55 mg/L), BHP1 (3.96 mg/L), BHP2 (3.80 mg/L) respectively. Water from BHA2 (3.10 mg/L) recorded the least (Table 3).

Water from WP2 (8.39 mg/L), had the highest amount of Nitrate followed by BHP1 (7.43 mg/L), WA1 (6.69 mg/L), WP1 (5.27 mg/L), BHA1 (3.07 mg/L), BHA2 (1.60 mg/L) and BHP2 (1.05 mg/L) respectively.

Water from BHP2 (0.30 mg/L) had the highest Nitrite with very low levels occurring in water from the other sources (Table 3). The differences were however not significant ($p = 0.1750$).

Table 3: Mean concentrations of Anions in water from boreholes and Hand-dug wells in Study communities

	Cl^- (mg/L)	F^- (mg/L)	NO_2^- (mg/L)	SO_4^- (mg/L)	NO_3^- (mg/L)
BHA1	12.89±0.86	1.80±0.09	0.0092±0.002	5.40±1.80	3.07±0.05
BHA2	15.40±3.00	0.42±0.07	0.0046±0.006	3.10±0.57	1.60±0.65
WA1	12.81±2.60	0.61±0.16	0.0014±0.001	10.39±1.20	6.69±0.41
BHP1	13.53±0.35	1.35±0.04	0.0078±0.004	3.96±0.84	7.43±0.75
BHP2	15.60±2.00	0.44±0.05	0.30±0.51	3.80±1.90	1.05±0.27
WP1	12.51±0.40	1.70±0.16	0.0054±0.004	13.14±0.50	5.27±0.12
WP2	17.76±0.52	1.64±0.14	0.0068±0.003	4.55±0.42	8.39±0.13
WHO Limit	**250 mg/L**	**1.5 mg/L**		**250 mg/L**	

4.1.9 Concentrations of Iron and Zinc

The Iron content in water ranged from a minimum of 0.06 mg/L for BHP2 to a maximum of 0.22 mg/L for water from BHA2 and WA1. The content recorded for WP2 was 0.21 mg/L followed by BHA1 (0.20 mg/L) and WP1 (0.16) respectively (Table 4). The iron contents for the water sources were beneath the WHO permissible limit of 0.3 mg/L for drinking water. Differences between means were not significant at $p \leq 0.05$.

The study showed that boreholes and hand-dug wells, in the sampling communities, had water with mean zinc level below 3.0mg/L, the WHO limit. Water from WP1 (0.58 mg/L) was noted for the highest amount of Zinc followed by that recorded for BHA1 (0.22 mg/L), BHA2 (0.20 mg/L), BHP1 (0.14 mg/L), WA1 (0.14 mg/L), WP2 (0.04 mg/L), respectively with BHP2 (0.03 mg/L) recording the least zinc content (Table 4).

Table 4: Mean concentrations of Iron and Zinc content of water from boreholes and Hand-dug wells in the study communities

	Fe (mg/L)	Zn (mg/L)
BHA1	0.20±0.024	0.22±0.380
BHA2	0.22±0.380	0.20±0.150
WA1	0.22±0.084	0.14±0.052
BHP1	0.07±0.029	0.14±0.037
BHP2	0.06±0.030	0.03±0.019
WP1	0.16±0.190	0.58±0.10
WP2	0.21±0.071	0.04±0.039
WHO Limit	**0.3 mg/L**	**3.0 mg/L**

4.2 Microbial Parameters

4.2.1 Total coliforms counts in water samples

The mean number of the total coliforms observed from the various water sources was 3.35×10^8 CFU. The highest mean number of total coliforms was obtained from WA1 ($2.34 \times 10^9 \pm 9.76 \times 10^7$) [Table 5]. The least mean total coliform count was observed for BHA2 (0.00×10^0 CFU). Analysis of variance yielded statistically significant difference ($p < 0.05$) between the observed total coliform count for water from the various sources.

Table 5: Mean counts of total coliforms from the various water sources

	Total coliform	
Water source	Mean count/ CFU	Standard deviation
BHA1	5.23×10^5	2.49×10^5
BHA2	0.00×10^0	0.00×10^0
WA1	2.34×10^9	9.76×10^7
BHP1	4.30×10^5	2.13×10^4
BHP2	3.06×10^4	4.50×10^3
WP1	8.97×10^5	3.59×10^4
WP2	8.99×10^5	3.72×10^4

4.2.2 Faecal coliforms counts in water samples

From Table 6, the mean faecal coliform count from the water sources was 1.62×10^{1} CFU (SD 3.25×10^{1}). The highest mean count was observed in water from WA1 (8.23×10^{1} CFU (SD 4.47×10^{1})) and the least mean count was observed in BHP2 (2.31×10^{-1} CFU (SD 2.01×10^{-1})). The mean faecal coliform count differed significantly for the different sources ($p=0.00$). Samples from BHA2 and BHP1 did not record any. (Table 6)

Table 6: Mean counts of faecal coliforms from the various water sources

Water source	Mean count/ CFU	Standard deviation
BHA1	4.60×10^{-2}	7.37×10^{-2}
BHA2	0.00×10^{0}	0.00×10^{0}
WA1	8.23×10^{1}	4.47×10^{1}
BHP1	0.00×10^{0}	0.00×10^{0}
BHP2	2.31×10^{-1}	2.01×10^{-1}
WP1	1.79×10^{1}	9.10×10^{0}
WP2	4.79×10^{1}	6.67×10^{-1}

4.2.3 Mean counts of *E. coli* counts in water samples

The total mean *E. coli* count was 2.77×10^{-1} CFU (SD 6.41×10^{-1}). The highest mean *E. coli* count was observed for WA1 (1.63×10^{0} CFU (SD 0.856)). Samples from BHA1 and BHA2 did not record any counts (Table 7). ANOVA yielded significant differences between the observed *E. coli* counts.

Table 7: Mean counts of E. coli from the various water sources

Water source	Mean count /CFU	Standard deviation
BHA1	0.00×10^{0}	0.00×10^{0}
BHA2	0.00×10^{0}	0.00×10^{0}
WA1	1.63×10^{0}	8.56×10^{-1}
BHP1	4.70×10^{-3}	9.21×10^{-3}
BHP2	2.60×10^{-3}	2.73×10^{-3}
WP1	1.67×10^{-1}	1.03×10^{-1}
WP2	1.31×10^{-1}	7.52×10^{-2}

4.2.4 Mean microbial counts in water in various homes

Table 8 below shows the mean microbial count at different homes based on their method of storage; either in coolers or plastic buckets. There was a generally high mean microbial count associated with water stored in plastic buckets than the water stored in the cooler in all cases. Statistical analysis revealed a significant difference ($p < 0.05$) between the various methods of water storage in the homes.

Table 8: Mean microbial count of storage water in various homes

			Mean microbial count / CFU		
			Total coliform	Faecal coliform	*E. coli*
SOURCE	Well		3.39×10^{5}	2.20×10^{-5}	1.82×10^{-5}
	Borehole		2.82×10^{5}	1.49×10^{-5}	1.63×10^{-5}
HOME	Well	Cooler	3.51×10^{5}	1.10×10^{-8}	1.01×10^{-9}
		Plastic bucket	4.13×10^{5}	1.30×10^{-5}	1.62×10^{-5}
	Borehole	Cooler	5.11×10^{7}	0.00×10^{0}	0.00×10^{0}
		Plastic bucket	6.98×10^{7}	0.00×10^{0}	0.00×10^{0}

CHAPTER FIVE

DISCUSSION

Ecosystems and human communities depend on the Earth's water cycle which is largely determined by evaporation and gravity, however, physicochemical processes are also involved in the transportation of many anthropogenic pollutants. Thus the quality of water and the hydrological budget is impaired due to stress on natural waters caused by activities of growing populations (Tack and Verloo, 1995).

It is imperative to put in place broad water quality monitoring regimes to identify impairments so as to put in measures to reduce the impact of anthropogenic activities on natural waters. Quantification of water quality can be accomplished by monitoring water resources. This will enable the formulation of appropriate land use policies to improve quality of life and preserve natural areas (Chapman, 1996). Indicators of water quality are classified into three categories namely; biological, chemical, and physical with each of the parameters under these categories having a set standard. Based on the WHO guidelines each country develops its own quality standards for drinking water. All domestic water supplies are checked against the set standards. The quality of water from four boreholes and three hand-dug wells within the Aboabo and Pataase communities were analyzed and the parameters measured against the WHO, USEPA, and NTU standard contaminant level for all drinking water.

5.1 Physicochemical parameters

Temperature: The most common of the parameters used in the determination of water quality is temperature. Temperature influences the chemical and biological features of surface water. It influences dissolved oxygen concentration in water, synthesis of organic molecules by aquatic plants, metabolic rates of aquatic organisms, and the response of aquatic biota to contamination, parasites and disease. Water temperature also can influence the chemical, bio-chemical characteristics of a water body. In this study the maximum temperature of 27.30 ^{0}C was recorded in the water from WP2 and a minimum of 25.34 ^{0}C was recorded in the water from BHP1. The temperature of water from Boreholes has generally been found to be in the range of 22 ºC -29 ºC. Water temperature in WP2, was high and could be due to its direct exposure to the sun, low water level, high temperature and direct matter exchange with the atmosphere (Salve and Hiware, 2008).

pH: The pH of a river or stream can provide information regarding various chemical and biological processes, and aids in assessing indirect associations to a number of different inconsistencies in water quality. The level of acidity or alkalinity also impacts the biological activity of algae (Villaverde *et al.*, 1997). Carbon dioxide reacting with water and also with the overlaying air, influences the pH in uncontaminated water (Pankow & Pankow, 1991).

All the pH values were slightly acidic (below 6.4). Water from WP2 recorded the least pH. When a water body records low pH values it is indicative of high hydrogen ions, which can be triggered by the deposition of caustic elements in rainfall. The observed pH levels were all below the WHO working limits of 6.5 and 8.5. The pH values below 6.5 have been observed as unideal for human use and may present adverse well-being conditions, a typical example being acidosis.

A shift of pH in favour of high acidity or high alkalinity may point to the presence of a contaminant in the water. However, due to the nature of water sources being naturally acidic or basic, pH may not essentially indicate contamination, but low pH levels can make some metals more soluble (Hujare *et al.*, 2008). This causes heavy metals to be easily taken up by living systems. The acidic nature of the values obtained suggests the presences of parent rock materials as a result of weathering.

Appearance/Colour: All water collected were within the permissible colour limits of WHO. The maximum value (21.29 CU) was recorded for the water from WP1 and the minimum value recorded for BHP1. Colour of water might not necessary be affected by some foreign materials as with case of suspended solids.

Total Dissolved Solids: There were usual total dissolved solid fluctuations. The highest total dissolved solid concentration (308.80 mg/L) was observed in water from WP1 which was within the range of WHO (500-1500 mg/L). This might be as a result of heavy rainfall with the least TDS concentration (40.36 mg/L) being observed in water from BHA2. High suspended solids recorded from water from WA1 compared to the others might be as a result of human activities due to its exposure and direct exchange of matter with the surrounding environment (Oviatt, 1997).

Turbidity: This is a measure of water transparency - the point to which light entering a column of water is dispersed by colloidal materials in water such as mud, algae, detritus, and fecal material. Turbidity reflects material deposits in water that affects the transparency or light scattering of the water. The range for natural water is 1 to 2000 NTU.

Total Suspend Solids (TSS) and Total Dissolved Solids (TDS) can be affected by changes in ionic species in water. Fluctuations in the ionic species of water can cause precipitation of dissolved substances or will affect the solubility of colloidal particles (Schwarzenbach *et. al*., 2003)

The turbidity of water fluctuates from 5-25 NTU according to World Health Organization (WHO). The maximum value of 5.02 NTU within the range of the study was recorded for water from WA1; it may be due to human activities, decrease in the water level and presence of suspended particulate matter compared to the rest and minimum value of 0.06NTU recorded for water from BHP2. All values within the range of WHO (Sen *et. al*., 2012).

A study conducted by Anyamwu (2011) in Nigeria, turbidity values observed depicted some sort of seasonal and spatial patterns; It was noted relatively higher turbidity values during the raining season period due to increased suspended solids loads in the run-off and subsequently attributed it to the level of human activity in the river system. Besides, higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria making the water unwholesome for drinking. These organisms can cause symptoms such as nausea, cramps, diarrhoea, and associated headaches.

Conductivity: The conduction of electrical current is the measurement of free ionizable solutes or ions in the natural water. Salts, for example sodium chloride and potassium chloride dissolved in water, generally create these ions. Many rivers and stream range between 0.1-10µs/cm (Ugwu and Wakawa, 2012). According to Figure 6, Water from WA1 had the highest conductivity of 581.22µs/cm with conductance of 393.00µs/cm for BHA1 and 379.00µs/cm for WP1. Higher values conductivity recorded can be attributed to run-off from the nearby farms as conductivity is an indirect measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron and aluminum (EU, 1998), which most of them are components of agrochemicals like pesticides and fertilizers.

Total alkalinity: The alkalinity of every water sources serves as the natural buffering capacity which may conceal the presence of acidic or basic pollutants (EPA, 2005). Alkalinity ranges between 20-200 ppm are common in freshwater sources with levels below 10 ppm indicating poorly buffered water source. These sources are the least capable of resisting changes in pH, therefore they are most susceptible to problems which due to the presence of acidic contaminants (EU, 1998; WHO, 2008).. The pH value is the best indicator of presence of acid or alkali in water samples. The alkalinity had maximum value with WP2 due to increase in bicarbonates in the water.

(Hujare, 2008) also reported similar results that it was maximum in summer and minimum in winter with surface water due to high photosynthetic rate. According to ISI, the acceptable limit of total alkalinity of drinking water sample is 500 mg/L and maximum desirable limit is 1500 mg/L. The levels measured in this study might have resulted due to leaching process through surface water during rainy season (Yerel, 2009).

Amount of Oxygen: Dissolved Oxygen (DO) is important to all forms of marine life including the organisms that break down man-made pollutants. The DO of fresh water at sea level will range from 150% at 0°C-80% at 25°C. The amount of contaminants present in fresh water will be close to 100% (Kannel *et al.*, 2007).

The Biological Oxygen Demand (BOD) may be the measure for oxygen needed to naturally break down a contaminant. It will be regularly utilized as an estimation of pollutants due to presence of contaminants. Also it helps evaluate the quality of wastewater, for example, that of sewage and mechanical emanating waters (Zeb *et al.*, 2011). BOD accordingly may be a critical parameter about water demonstrating those wellbeing situation about freshwater forms. (Bhatti and Latif, 2011).

The chemical oxygen demand, or COD, is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.

In the present study water from BHP1 had the highest chemical oxygen demand of 1.11 mg/L with the least being WP1 (0.72 mg/L), BHA2 (1.06 mg/L) had the highest BOD with the least being WP2 (0.41 mg/L), whereas there was high Dissolved Oxygen recorded in water from BHA2 (3.54 mg/L) with the least recorded from BHA1 (2.62). Zeb *et al.,* (2011) explained that DO levels are important in the natural self-purification capacity of a river. A good level of DO in sampling sites indicated a high re-aeration rate and rapid aerobic oxidation of biological substances. As it is graphically shown from the Figure 2, all the different sources had Dissolved Oxygen the highest, followed by the chemical Oxygen demand and the Biological Oxygen demand the least. Manjare *et al.,* (2010) attributed elevated DO in the summer to an increased temperature and period of bright sunlight which might have had a direct influence on the % of soluble gases (O_2 and CO_2), hence, might have had a proportionate characteristics with the present study.

Hardness of water: Potable water is expected to have hardness lower than 300mg/L, beyond which irritation of the gut may occur (Chaurasia *et al.,* 2007). This suggest that, all the water sources are within the permissible range recommended by the ICMR and Bureau of Indian Standards (BIS) of 300 mg/L, since all the recorded values fell below the limit. The value of hardness ranged from 34.20 to 70.99. The highest concentration (70.99 mg/L) observed in the water from BHA1 and least concentration (34.20 mg/L) for water from BHA2, however, all were below the recommended permissible range of 8.0 to 103mg/L by the World Health Organization, WHO, hence very wholesome for drinking in terms of hardness of these water sources.

Salinity: All values of salinity recorded were within the permissible limits of WHO, with the exception of that from WP2 with little above limit. This is evidence of its high saltiness at the time of collection (WHO, 1979).

Fluoride and Chloride: Fluoride is vital for living organisms as a trace metal and higher amounts of this element causes toxic effects. Concentration of fluoride between 0.6-1.0 mg/l in potable water protects tooth decay and enhances bone development (Kundu *et. al*., 2001). Range of fluoride recorded for the different water sources were within that of WHO range (Sen *et. al*., 2012). Chlorides are essential inorganic anions which is in variable concentrations in rivers and lakes (Makhoukh, *et al.,* 2011). Chlorides are toxic to plant if used as irrigation water and may also injurious to marine life (Rajkumar, *et al.,* 2004). High concentration of chloride is considered to be the indicators of pollution due to organic wastes of animal or industrial origin. High chloride content of water indicates organic pollution of animal origin (Bourrelly, 1966). There was high chlorine recorded in all cases of the different water source compared to fluoride (within WHO limits) [WHO, 2006]. This is an indicative of high salinity as a result of the chemical interaction with sodium to form sodium chloride ($NaCl_{(aq)}$).

Iron: The presence of iron (Fe) may increase the hazard of pathogenic organisms; since most of these organisms need Fe for their growth (Tiwana *et al.*, 2005). The iron (Fe) values of the different sites of river water samples were found lower than the permissible limit of standards for drinking water (500 µg/L) [WHO, 2006].

Most ferrous compounds in aquatic environments are resulting from the precipitation of Fe in alkaline and oxidizing conditions (Abdulla *et. al*., 1973). Most Fe is found as different forms of Fe oxides like hematite, magnetite, and taconite (Edwards, 2010). Another reason for the increase in Fe content might be due to the run off from domestic wastes and other urban wastes (Neal *et. al*., 2000). The highest amount of iron present was recorded in the water from BHA2 and WA1 and the minimum from BHP1.

Zinc: Zn is an enzyme co-factor in several enzyme systems including carbonic anhydrase found in red blood cells. The Zn values of the different water sources were found a lower the permissible limit of (standards for drinking water (1000 µg/L) [WHO, 2006].

Zn is naturally found in air, water, and soil. Zn concentrations are rising due to additions of Zn to the environment industrial activities like mining, coal, waste combustion, and steel processing (Edwards, 2010).

Anions: Nitrate concentrations greater than 10 mg/L in rivers normally indicate man-made contamination. Man-made sources of nitrate include, fertilizers, livestock, urban runoff, septic tanks and effluents. When many lands are converted into agricultural land and as metropolitan areas expand, nitrate checking is a vital tool in accessing, locating and moderating man-made sources of nitrate. Man-made sources of nitrate in the environment include household and manufacturing discharges and agricultural runoff where manures are used.

The amount of different forms of nitrogen gives a useful signal of the level of micro-nutrients in the river and hence their ability to maintain plant growth. The prescribed limit of NO_3^+ by WHO is 50 mg/l for domestic water. All range of nitrate recorded were within perimeters.

The incidence of sulphate has less consequence on the taste of water compared to the presence of chloride. The required limit of sulphate in potable water prescribed by ICMR is 200-400 mg/l. The increased concentration of sulphate may induce diarrhoea and intestinal disorders. Excess amount of sulphate in water has cathartic effect of human health.

5.2 Biological parameters

Total and faecal coliform, *E. coli*: The mean number of the total coliforms observed from the various water sources was 3.35×10^8. The highest mean number of total coliforms was obtained from WA1 ($2.34 \times 10^9 \pm 9.76 \times 10^7$). The least mean total coliform count was observed for BHA2 (0.00×10^0). Anova yielded statistically significant difference ($p<0.05$) between the observed total coliform count for water from the various sources. The highest mean count for faecal coliform was observed in water from Well water WA1 and the least mean count was observed in BHP2 as in Table 3. Again, from Table 4, the total mean *E. coli* count was $2.77 \times 10^{-1} \pm 6.41 \times 10^{-1}$. The highest mean *E. coli* count was observed for WA1 (1.63 ±0.856). Samples from BHA1 and BHA2 did not record any counts. The recorded values of total and faecal coliform, and *E. coli* in these water source measured against the zero maximum contaminant level (MCL) recommended by USEPA and WHO, is an indication of a possible presence of both human and animal faecal waste in these water sources. Although primarily non-pathogenic, their presence refers to the presence of disease-causing organisms. They reach natural waters mainly during rainfall, through runoff from agricultural and urban lands as well as through drainage (Medema *et al.*, 2003). Total and faecal coliforms as indicators of previous and new faecal pollution, are often used as indicators of microbial water quality (Rompré *et al.*, 2002). Total coliform is used as a parameter giving basic information on microbiological quality of surface waters (WHO, 2008).

Drinking water storage strategies in various homes influences the microbial activities as this can be seen from the mean microbial count of the water stored in coolers and that stored in plastic buckets. High mean microbial count recorded from water stored in plastic buckets might be attributed to its openness or exposure to the surrounding environment. Exchange of matter between in and outside of plastic buckets affect both the biological and chemical oxygen which hence shoots the biological activities up (Geldreich, 1996). Water stored in coolers had recorded values of moderate mean around that of the source which might be as a result of low or equal microbial activities comparably. Safety of water stored in coolers over plastic buckets played a factor role in the final mean microbial count (Levy *et. al.*, 2008).

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study presented the biological and physicochemical parameters (total coliform, faecal coliform, *E. coli*, pH, temperature, turbidity, conductivity, alkalinity, hardness of water, amount of oxygen) of water samples from the hand-dug wells and boreholes located in Aboabo and Pataase in the Jacobu traditional area.

Most of the physicochemical parameters were found to be within the permissible range recommended by the WHO. However pH values were all below the recommended range set by the WHO whilst turbidity for WA1 was above the WHO limit.

Water from hand-dug wells were contaminated with Total coliforms, faecal coliforms as well as *E. coli* revealing statistically significant differences (p=0.001) between the observed counts for water from the various sources. This indicates that water from all the hand-dug wells in the study communities are not wholesome for and must be treated before drinking.

6.2 Recommendation

On the basis of the findings of this study it is recommended that:

i. Intensification of education and implementation of regulations on safe drinking water by the Ghana Standards Board, the Ghana EPA and district environmental units and other state enforcements agencies will go a long way to reduce incidences of water pollution and the associated water borne diseases.

ii. The inhabitants of these two communities (Aboabo and Patase) must be encouraged to adopt and practices of small scale treatment of water such as boiling and filtration methods to improve the wholesomeness of their drinking water.

iii. Further research on other communities within the Jacobu traditional area for the assessment of the quality of drinking water is required as levels of contaminants may vary due to different soil types, water chemistry and different human activities.

REFERENCES

Abdulla M. I, Dunlop H. M and Gardner D (1973). Chemical and hydrographic observations in the Bristol Channel during April and June 1971, *J. Mar. Biol. Assoc. U. K.* 36:509–17.

Abdus-Salam, N. and Adekola F. A (2005). The influence of pH and adsorbent concentration on adsorption of lead and zinc on a natural goethite. African J. Sci. Technol. (AJST), **6***(2):* 55-66

Adetunde, L. A. and Glover, R. L. K. (2010). Bacteriological Quality of Borehole Water Used by Students' of University for Development Studies, Navrongo Campus in Upper-East Region of Ghana. *Current Research Journal of Biological Sciences* 2(6): 361-364.

Akoto O. and Adiyah J. (2007). Chemical analysis of drinking water from some communities in the BrongAhafo Region. *International Journal of Environment Science and Technology* **4**(2): 211-214

Amdur, M. O., Dull, J. and Klaasen, C. (1991). *Casarett and Dull's Toxicology*, the Basic Science of poisons.Pergamon Press, New York, 639-643

APHA (1992). *Standard methods for the examination of water and wastewater.*18th ed. American Public Health Association, Washington, DC.

Appelo, C. A. J. and Postma, D. (1993). Geochemistry, Groundwater and Pollution. 76, 536 pp. Rotterdam, Brookfield.

Asklund, R., and Eldvall, B. (2005). Contamination of water resources in Tarkwa mining area of Ghana. A Minor Field Study for Master of Science Thesis, Royal Institute of Technology, Department of Engineering Geology Lund University, Lund, pp.3-8.

Atafar Z, Mesdaghinia A, Nouri J, Homaee M, Yunesian M, Ahmadimoghaddam M and Mahvi H. (2010). Effect of fertilizer application on soil heavy metal concentration. *Environ Monit Assess* 160: 83–89.

Ayedemi, O., Oloyede, O. B., Oladiji A. T. (2007). Physiochemical and Microbial Characteristics of Leachate Contaminated Groundwater. Asian J. Bioch., 2(5):343-348

Bagenal T. B. (1978). *Fecundity in Eggs and Early Life History (Part 1)* In: Bagenal TB (Ed), Methods for Assessment of Fish Production in Freshwaters..3rd edition, Blackwell Scientific Publications, Oxford and Edinburgh, 166 - 178.

Barrett, M. H., Johal, K., Howard, G., Pedley, S. and Nalubega, M. (2000) Sources of faecal contamination in shallow groundwater in Kampala. In: Groundwater: Past Achievements and Future Challenges. Amsterdam, The Netherlands: Balkema Publishers; pp 691-696.

BIS (1993). Analysis of water and waste water.Bureau of Indian Standards, New Delhi.

Bourrelly P, (1966) Les Algues D'eau Douce. Initiation `a La Syst´ematique. Tome I: Les Algues Vertes, Boub´ee et Cie, Paris, France.

British Colombia Ministry of Health, (1999)."Safe Water Supply Vital to Your Health." http://www.healthservices.gov.bc.ca/protect/pdf/PHI052.pdf. Accessed on 24-02-2013.

Bruntland, G. H. (1987). *Our Common Future,* Report of the World Commission on the Environment and Development. Oxford University Press, Oxford, U.K.

Center for Disease Control and Prevention, (2013). "Salmonella and Drinking Water from Private Wells" .http://www.cdc.gov/ncidod/dpd/healthywater/factsheets / salmo nella.htm (Accessed on 24/01/13).

Chapman, D. (1992). Water Quality Assessment; A guide to the use of biota, sediments and water in environmental monitoring. University Press, Cambridge, pp.585.

Chapman, D. V. (Ed.). (1996). Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. 2nd Edn. E & F Spon, London

Charles, E. G., Behroozi, C., Schooley, J., and Hoffman, J. L. (1993). A Method for Evaluating Ground-Water-Research Areas in New Jersey. New Jersey Geological Survey Report GSR-32. New Jersey Department of Environmental Protection and Energy. pp 103

Chaurasia M. and Pandey G.C. (2007). Study of physico-chemical characteristic of some water ponds of AyodhyaFaizabad.*Indian J. of Environ. Protect.*, 27(11), 1019-1023

Dick, L. K. and Field, K. G. (2004). Rapid estimation of numbers of fecal Bacteroidetes by use of a quantitative PCR assay for 16S rRNA genes. *Appl. Environ. Microbiol*. 70**(9)**, pp: 5695-5697

ECLAC (1989). The Water Resources of Latin America and the Caribbean: Water Pollution. LC/L.499, United Nations Economic Commission for Latin America and the Caribbean,United Nations, Santiago de Chile.

Edema, M. O., Omemu, A. M. and Fapetu, O. M. (2001). Microbiology and Physicochemical Analysis of different sources of drinking water in Abeokuta, *Nigeria.J. Microbiol*. **15***(1)*: 57-61.

Edwards P. K. (2010). The Correlation of the Concentration of Selected Metals Determined in Water and Fish Samples from a Public Pond, Electronic Thesis and Dissertations, Digital Commons @ East Tennessee State University, East Tennessee State University

Edwards, D.D. (1993). Trouble Waters in Milwaukee. *Am. Soc.Microbial.* News, **59**:342

Emeka, D. A., (2011). Physico-Chemical and Some Trace Metal Analysis of Ogba River, Benin City, Nigeria.*Jordan Journal of Biological Sciences, 5*, pp: 47 - 54

Enderlein, R. E. (1996). Protection and sustainable use of waters: agricultural policy requirements in Europe. HRVAT. VODE, **4***(15)*, 69-76.

EPA (2005). Environmental Protection Agenc.y .Protecting water quality from Agricultural Runoff. Fact sheet No. EPA-841-F-05-001.

European Union [EU], (1998). Drinking Water Standard Comparative Task.

Falkenmark, M. (2005). Water usability degradation – economist wisdom or societal madness?*Water International*, **30***(2):* 136 -146.

Fatoki, O.S., Lujiza, N. and Ogunfowokan, A. O. (2002). Trace metal pollution in Umtata, River. Water SA, **28***(2)*: 183-189

Geldreich, E. E. (1996). *Microbial quality of water supply in distribution systems*. CRC Press.

Gibbs, R. J. (1970). *Mechanisms controlling world water chemistry*. Science 170: 1088–1090.

Gleick, P. H. (1996). Water resources. In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, *vol. 2,* pp.817-823

Gundry S, Wright J, and Conroy R, (2004). A systematic review of the health outcomes related to household water quality in developing countries. *J Water Health 2:* 1–13.

Hardy, H. D., Jeana, M. and Stokes, C. (2008). Heavy Metals in North Carolina soils: Occurrence and significance. Department of Agriculture and consumer Services. www.ncagr.gov/agronomi.com (accessed 2009 May 19 at 3:24 PM).

Herschy, R. W. (1999). Hydrometry: Principles and Practices. 2nd Edition. John Wiley and Sons, Chichester. 200p.

Hesterberg, D. (1998). Biogeochemical cycles and processes leading to changes in mobility of chemicals in soils. *Agric. Ecosyst. Environ.* 67: 121–133

http://water.epa.gov/learn/resources/bigpollutants.cfm. Assessed: Feb. 24 2014

http://water.epa.gov/type/rsl/monitoring/vms52.cfm. Assessed: March 28 2014

http://water.usgs.gov/edu/watercyclestreamflow.html, Retrieved: Tuesday, 15-Apr-2014

http://www.dwaf.gov.za/Dir_WQM/wqm.asp. Assessed: April. 24 2014 http://www.safewater.org. Assessed: Feb. 24 2014

Hujare, M. S. (2008). Seasonal variation of physico-chemical parameters in the perennial tank of Talsande, Maharashtra. Ecotoxicol. Environ. Monitor. 18(3): 233-242.

ICMR (1975). Manual of standards of quality for drinking water supplies. ICMR, New Delhi.

ICWE Secretariat, (1992).International Conference on Water and the Environment. Keynote Paper, Dublin, Ireland, WHO, Geneva, Switzerland

Iscen C. F, Emiroglu O., Ilhan S., Arslan N., Yilmaz V., and Ahiska, S. (2008). Application of multivariate statistical techniques in the assessment of surface water quality in Uluabat Lake, Turkey.*Environ Monitoring and Assessment*, **144** *(1-3)***:** 269-276.

Kara, Y., Kara, I. and Basara, D. (2004). Investigation of Some Physical and Chemical Parameters of Water in the Lake Isykli in Denizli, Turkey.*International Journal of Agriculture and Biology***6**(2): 275-277.

Karanth, K.R (1987): Groundwater Assessment Development and Management Tata McGraw Hill Publishing company Ltd., New Delhi, 725p.

Keller, A., Abbaspour K. C. &Schulin R. (2002). Assessment of Uncertainty and Risk in Modeling Regional Heavy-Metal Accumulation in Agicultural Soils.*J. Environ. Qual*., 31: 175-187.

Koryak, M., (1997). Origins and ecosystem degradation impacts of acid mine drainage. U.S. Army Corps of Engineers. Available at http://www.army.mil/misc/AMD_Impacts.htm. Accessed (24/11/2007).

Langmuir, D. (1997). *Aqueous Environmental Geochemistry*. Prentice-Hall, New York.

Lester, J. N. and Birkett, J. W. (1999). *Microbiology and Chemistry for Environmental Scientists and Engineers*, 2nd edn. E and FN Spon, NewYork.

Levy, K., Nelson, K. L., Hubbard, A., and Eisenberg, J. N. (2008). Following the water: a controlled study of drinking water storage in northern coastal Ecuador. *Environ Health Perspect*, *116* (11), 1533-1540.

Liang, C., Das, K. C., and McClendon, R. W. (2003). The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend. *Bioresource Technology*, *86*(2), 131-137.

Makhoukh M., Sbaa M, Berrahou, A., and Van Clooster, M. "Contribution `a l'´etude physico-chimique des eaux superficielles de l'Oued Moulouya (Maroc oriental)," *Larhyss Journal*, no. 9, pp. 149–169, 2011.

Manjare, S. A. Vhanalakar, S. A. and Muley, D. V. (2010). Analysis Of Water Quality Using Physico-Chemical Parameters Tamdalge Tank In Kolhapur District, Maharashtra. International Journal of Advanced Biotechnology and Research ISSN 0976-2612, Vol 1, Issue 2, pp 115-119

Medema G. J., Shaw S, Waite M, Snozzi M, Morreau A., and Grabow W. (2003). Catchment characterization and source water quality. In Dufour et al. (eds) Assessing Microbial Safety of Drinking Water: Improving Approaches and Methods, WHO, OECD, London,pp. 111–158.

Meybeck, M. and Helmer, R. (1996). Introduction. In: D. Chapman [Ed.] Water Quality Assessments. A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring.2nd edition. Chapman & Hall, London

Millennium Development Goals African, (2008). Achieving the Millennium Development Goals in Africa.The MDG Africa Steering Group. Press release, 1st July, 2008 United Nations. Retrieved 2nd February, 2014 www.mdgafrica.org/achieving_mdg.html

Ministry of Works and Housing, Ghana, (1998). Water Resources Management (WARM) study – information building block. Accra, Ghana. Monitoring and Geochemistry. Bull. Chem. Soc. Ethiop., **14***(1)*: 1-8.

Munawar, M. (1970). Limnological studies on freshwater ponds of Hyderabad-India I. The Biotope. *Hydrobiologia*, *35*(1), 127-127.

National Water Policy, **(2007)** Government Of Ghana, Ministry of Water Resources, Works and Housing, pp 1-13

Neal C., Jarvie, H. P,, Whitton B. A, and Gemmell J (2000). The water Quality of the river Wear north-east England. *Sci. Tot. Environ*. 51/252: 153-172. Doi: 10, 1016/S0048-9697 (00) 00408-3

Obiri- Danso, K., Adonadaga, M. G., and Hogarh, J. N. (2010). Effect of Agrochemical Use on the Drinking Water Quality of Agogo, a Tomato Growing Community in Ashanti Akim, Ghana. Bull Environ. Contam.Toxicol 86: 71-77

Oladipo C, Onyenike I.C, and Adebiyi A.O (2009). Microbiological analysis of some vended Sachet water in Ogbomoso, Nigeria. *Afr. J. Food Sci*. 3(12):406-412.

Olajire, A. A. and Imeokparia, E. E. (2000). A Study of the Water Quality of the Osun River: Metal Monitoring and Geochemistry. *Bull. Chem. Soc. Ethiop*., **14***(1):* 1-8.

Oregon Department of Environmental Quality, (2004).Assessment Methodology for Oregon's 2004 Integrated Report on Water Quality Status. Retrieved March 22, 2006. http://www.deq.state.or.us/wq/303dlist/docs/AssessmentMethodology2004.pdf

Oswald W. E., Lescano A. G., Bern C., Calderon M. M., Cabrera L., and Gilman R. H. (2007). Fecal Contamination of Drinking Water within Peri-Urban Households, Lima, Peru. *Am. J. Trop. Med. Hyg.*, 77(4), pp. 699–704

Pankow, J. F., and Pankow, J. F. (1991). *Aquatic chemistry concepts* (pp. 219-242). MI: Lewis Publishers. Chelsea.

Pearce, G. R., Ramzan Chaudhry, M. and Ghulam, S. [Eds.], (1999). Department for International Development Wallingford. DFID.A Simple Methodology for Water Quality Monitoring. *Indian J. of Environ. Protect.*, 27(11), 1019-1023

Prat, N and Munne A., **(2000).** Water use and quality and stream flow in a Mediterranean stream. *Water Res.,* **34 (15):** 3876-3881.

Quilbe, R. P., Wicherek, S., Dugas, N. Tasteryre, A., Thomos, & J. Qudinet, J. (2004). Combinatory Chemical and Biological Approaches to Investigate Metal Elements in Agricultural Run-off Water .*J. Environ. Qual. 33*: 149-153.

Rajkumar S., P. Velmurugan, K. Shanthi, P. M. Ayyasamy, and P. Lakshmanaperumalasamy, (2004) "Water quality of Kodaikanal lake," in *Tamilnadu in Relation to Physico-Chemical and Bacteriological Characteristics*, pp. 339–346, Capital Publishing Company, Lake,.

Salve, V. B. and Hiware C. J. (2008): Study on water quality of Wanparakalpa reservoir Nagpur, Near Parli Vaijnath, District Beed. Marathwada region, J. Aqua. Biol., 21(2): 113-117.

Scheinberg, H. T., (1991). Copper, In: E. Merian, (ed). Metals and their compounds in the Environment: Occurrence, Analysis and Biological Relevance. VCH, New York, 803-851.

Schwarzenbach, R. P., Gschwend, P. M. and Imboden, D. M. (2003). Environmental Organic Chemistry, 2nd Ed.. John Wiley & Sons, Inc. New York

Sen, S., Paul, M. K., and Borah, M., (2012). Study of some physico-chemical parameters of pond and river water with reference to correlation study. *International Journal of Chem.*, 3 (4),1802-1807

Sood, A, Singh, K. D., Pandey, P., and Sharma, S. (2008). Assessment of bacterial indicators and physicochemical parameters to investigate pollution status of Gangetic river system of Uttarakhand (India).*Ecological Indicators,* **8**: 709-717.

Spear, P. A. (1981). Zinc in the Aquatic Environment: Chemistry, Distribution and Toxicology. Natural.Research council of Canada Associate Committee on Scientific Criteria for Environmental Quality. Report No 17589. Ottawa

Tack, F. M. G., and Verloo, M. G. (1995). Chemical speciation and fractionation in soil and sediment heavy metal analysis: a review. *International Journal of Environmental Analytical Chemistry, 59*(2-4), 225-238.

Telmer, K. H. and Veiga, M. M. (2008). Mercury Management in ASM Gold Mining Proceedings of Pre-Conference Technical, Consultative and Collaborative Session; 8thAnnual Communities and Artisanal & Small Scale Mining (CASM) ConferenceDate: October 7, 2008. Brasilia, Brazil. Pp: 1-13

Tiwana NS, Jerath N, Singh G, Ravleen M(2005). 'Heavy metal pollution in Punjab rivers', in Newsletter Environmental Information System (ENVIS). 3(1):3–7, Punjab State Council for Science and Technology, India.

Tortora, J. G, Funke R.B and Case LC (2002) Microbiology; An introduction. Media update of 7th Edn. Including Bibliography and index Publisher. Daryl fox. pp. 258-260.

Trevett A. F., Carter R. C., and Tyrrel S. F., (2005). The importance of domestic water quality management in the context of faecal oral disease transmission. *J Water Health 3:* 259–270.

Tuzen, M., Aydemir, E. and Hayati, S. (2002). Investigation of some physical and chemical parameters in the Lake Isykli in Denizli, Turkey.Fresen Environ Bull., 11: 202 – 207.

Ugwu, A. I. and Wakawa R. J. (2012) A Study Of Seasonal Physicochemical Parameters in River Usma, *American Journal of Environmental Science*, **8** (5), 569-576

UNECE (1992) Convention on the Protection and Use of Transboundary Watercourses and International Lakes, Helsinki, 17 March 1992, United Nations Economic Commission for Europe, United Nations, New York and Geneva.

United Nations, (1994) Consolidated List of Products Whose Consumption and/or Sale Have Been Banned, Withdrawn, Severely Restricted or Not Approved by Governments. Fifth issue, ST/ESA/239, United Nations, New York.

Venkatasubramani, R., and Meenambal, T. (2007). Study on subsurface water quality in Mettupalayam taluk of Coimbatore district, Tamil Nadu. *Nature, Environment and Pollution Technology*, *6*(2), 307-310.

Verma, B. L. and Srivastava, R. N. (1990). Measurement of the Personal Cost of Illness due to some Major Water-related issues in an Indian Rural Population.*Int. J. Epidemiol*. **19**: 169–176

Villaverde, S., Garcia-Encina, P. A., and Fdz-Polanco, F. (1997). Influence of pH over nitrifying biofilm activity in submerged biofilters. *Water Research*, *31*(5), 1180-1186.

Walker, H. and Sibly, P. (2001). *Principles of Ecotoxicology*, Taylor and Francis, London.

Water Resources Commission [WRC] (2000). Report on water resources management problems identification and prioritization. Accra, Ghana.

Welch P, David J, Clarke W, Trinidade A, Penner D, **Bernstein S, McDougall L. and Adesiyun A. A. (2000).** Microbial quality of water in rural communities of Trinidad. Rev Panam Salud Publica/Pan Am J Public Health 8 (3):172–180.

WHO (1996). Guideline for Drinking Water Quality, 2nd edn.WHO, Geneva. pp. 351–354.

WHO (2004a). www.who.int/water_sanitationhealth/publications/facts2004/en/ Assessed: 20th April 2014

WHO (2004b). WHO Guidelines for drinking water quality, 3rd. ed. Volume 1.World Health Organisation – Geneva.

WHO (2006). Guidelines for Drinking Water Quality Vol. 1. Recommandations, World Health Organization, Geneva, Switzerland, 3rd edition.

WHO (2008). Guidelines for Drinking-water Quality (3rd ed., incorporating first and second addenda). World Health Organization Press, Switzerland.1:281-294.

WHO/UNICEF (2010). Joint Monitoring Programme for Water Supply and Sanitation ; Progress on Sanitation and Drinking Water (2010 Update), WHO library Cataloguing- In Publication. ISBN 978 92 4 156395 6

World Health Organization and UNICEF (2006). Meeting the MDG drinking water and sanitation target : the urban and rural challenge of the decade. http://www.who.int/ water sanitation_health/monitoring/jmpfinal.pdf. Assessed: Jan. 16, 2014

World Health Organization, (1996) Water quality assessments: A guide to the use of biota, sediments and water in environmental monitoring, 2nd ed, Edited by Deborah Chapman,.

Yerel S. (2009). Investigation of Water Quality Characteristics by Using Factor and Multidimensional Scaling Analyses in Porsuk River (Turkey). *Asian Journal of Chemistry*, Vol. 21(9), 7234-7240

Zeb B S, Malik A H, Waseem A and M Q (2011) Water quality assessment of Siran river, Pakistan. International Journal of the Physical Sciences Vol. 6(34), pp. 7789 - 7798,

APPENDICES

ANOVA TABLES FOR PHYSICOCHEMICAL PARAMETERS

Parameter Table Analyzed	Ca^{2+}		
One-way analysis of variance			
P value	**< 0.0001**		
P value summary	***		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	197		
R square	0.98		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	751	6	125
Residual (within columns)	18	28	0.63
Total	768	34	

Parameter Table Analyzed	Cl^-		
One-way analysis of variance			
P value	**0.0003**		
P value summary	***		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	6.4		
R square	0.58		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	114	6	19
Residual (within columns)	84	28	3.0
Total	198	34	

Parameter Table Analyzed	NO_3^-		
One-way analysis of variance			
P value	**0.1750**		
P value summary	**ns**		
Are means signif. different? (P < 0.05)	No		
Number of groups	7		
F	1.6		
R square	0.26		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	0.37	6	0.061
Residual (within columns)	1.0	28	0.037
Total	1.4	34	

Parameter Table Analyzed	**Fe**		
One-way analysis of variance			
P value	**0.5245**		
P value summary	**ns**		
Are means signif. different? (P < 0.05)	No		
Number of groups	7		
F	0.88		
R square	0.16		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	0.15	6	0.024
Residual (within columns)	0.78	28	0.028
Total	0.93	34	

Parameter Table Analyzed	F^-		
One-way analysis of variance			
P value	**< 0.0001**		
P value summary	*****		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	155		
R square	0.97		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	12	6	1.9
Residual (within columns)	0.35	28	0.012
Total	12	34	

Parameter Table Analyzed	SO_4^{2-}		
One-way analysis of variance			
P value	**< 0.0001**		
P value summary	*****		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	53		
R square	0.92		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	446	6	74
Residual (within columns)	39	28	1.4
Total	486	34	

Parameter Table Analyzed	NO_4^-		
One-way analysis of variance			
P value	**< 0.0001**		
P value summary	*******		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	235		
R square	0.98		
ANOVA Table	**SS**	**df**	**MS**
Treatment (between columns)	255	6	42
Residual (within columns)	5.1	28	0.18
Total	260	34	

Parameter Table Analyzed	Zn^{2+}		
One-way analysis of variance			
P value	**0.0002**		
P value summary	*******		
Are means signif. different? (P < 0.05)	Yes		
Number of groups	7		
F	6.5		
R square	0.58		
ANOVA Table	SS	df	MS
Treatment (between columns)	1.0	6	0.17
Residual (within columns)	0.75	28	0.027
Total	1.8	34	

ANOVA TABLE FOR BIOLOGICAL PARAMETERS

Number of colony forming units

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3668005851757151700.000	2	1834002925878575870.000	8.008	.001
Within Groups	32978005841595388000.000	144	229013929455523520.000		
Total	36646011693352540000.000	146			